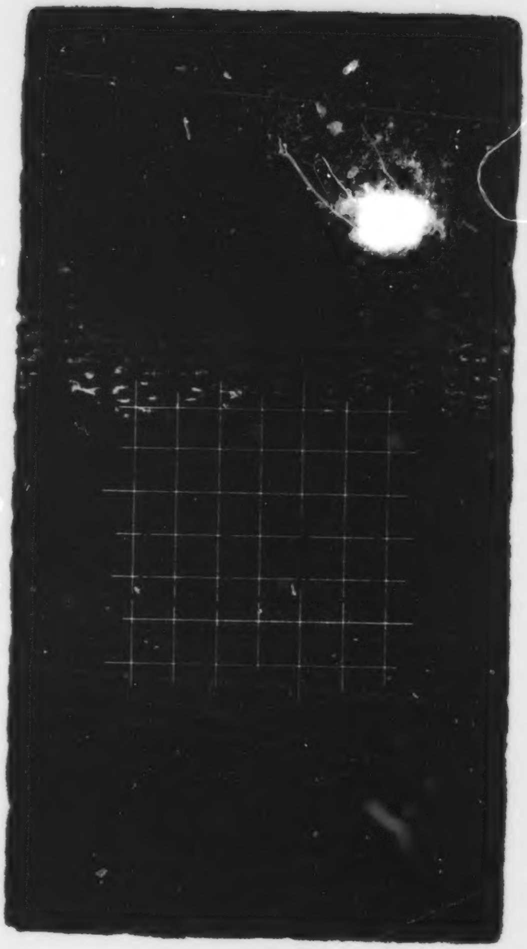

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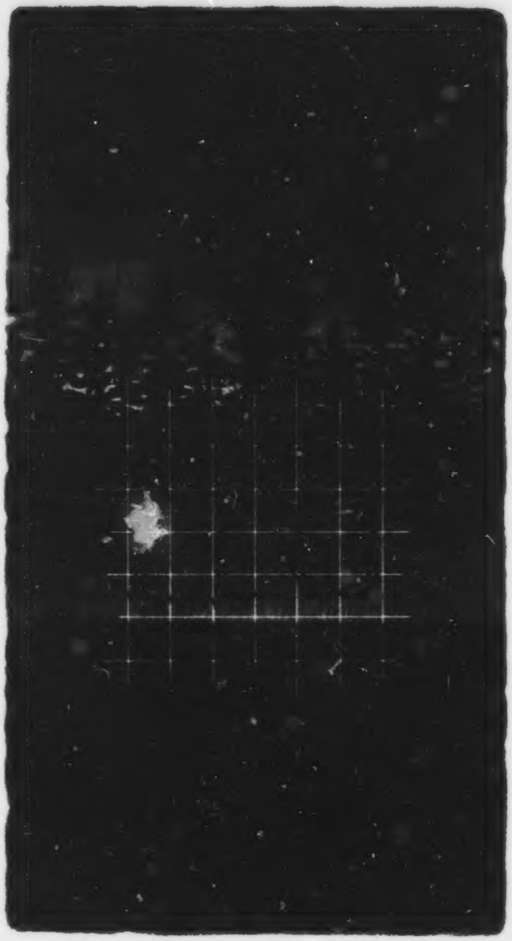

THE · STATE · OF
CANADA'S
ENVIRONMENT

Government of Canada

Ottawa
1991

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This book has been produced with both the environment and the reader in mind. The design optimizes the amount of text and graphics and minimizes unused space, while incorporating sufficient white space to be visually attractive. The Times type face and three-column format allow for easy-to-read text and flexibility in illustrations. According to the definitions in the Environmental Choice Program, the text and endleave papers and the binders board used in this publication all contain a minimum of 50% post-consumer and post-commercial recycled fibres, of which at least 10% is of the post-consumer variety. The printing has been done with vegetable oil-based inks.

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MINISTER'S MESSAGE

On any long journey, travellers look for signposts that mark the direction to follow and the distance yet to go. In 1990, *Canada's Green Plan for a Healthy Environment* committed us to a path toward sustainable development. The achievement of sustainable development - a strong and prosperous economy and a healthy and vibrant natural environment - is a long journey that will involve many changes in how Canadians think and act with respect to the natural environment. *The State of Canada's Environment - 1991* is an important signpost along the way.

For millennia, human activities had a negligible impact on the planet. With the onset of the Industrial Revolution, society's ability to alter the environment began to increase rapidly. We have now reached the point where the cumulative decisions of billions of people are affecting every part of the world.

Canada's Green Plan recognizes that, as caretakers of a significant proportion of the planet's air, water, land, and wildlife, Canadians have an important responsibility to make careful choices about the environment. People across Canada are rising to the challenge of sustainable development and are seeking accurate, up-to-date information about the state of the environment to help them make better decisions in all aspects of their lives.

This second national state of the environment report was prepared with contributions from more than one hundred experts from universities, private industry, environmental groups, and governments. A Public Advisory Committee of specialists from across Canada helped to shape the report's conceptual framework and assess its contents. Many others from research institutes, environmental groups, and economic sectors reviewed draft chapters. That cooperative partnership has ensured a more balanced, objective, and comprehensive report than could be produced by any single interest.

Jean J. Charest

Jean J. Charest
Minister of the Environment

The report addresses four fundamental questions: What are the key environmental conditions and trends in Canada? What are the links between human activities and environmental changes? What are the ecological, economic, and health implications of these changes? And, what are Canadians doing to address the concerns that have been identified?

The following pages succeed in providing some, but not all, of the answers. That partial success underscores the fact that, although Canada is making some progress, we need both more information and more action to move us closer to our goal.

I am pleased to present *The State of Canada's Environment - 1991* to the Canadian public. To the many contributors, I offer my warmest thanks. And to all Canadians, I issue a challenge - the challenge of putting this information to good use. The report analyzes and summarizes a wealth of knowledge; let us each *use* it to help protect the environment and safeguard our future.

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The environment is our only life-support system. As we approach the twenty-first century, however, there are indications that we are severing this lifeline.

The Government of Canada underscored its commitment "to secure for current and future generations a safe and healthy environment and a sound and prosperous economy" in the Green Plan announced in December 1990. It recognizes that access to credible, balanced information is the best foundation for environmental awareness and decision-making, if Canada's natural, economic, and cultural heritage is to be sustained.

Canada, like many other countries, has implemented a State of the Environment (SOE) Reporting program. Prepared for Canadians interested in their environment, SOE Reporting takes many forms: fact sheets, special reports, newsletters, environmental indicators, a data-base, and national reports that appear once every five years.

These products are the result of an increasingly strong partnership involving federal, provincial, and territorial governments, private industry, academia, nongovernmental organizations, and individual Canadians. Because the environment is affected by decisions and activities undertaken at all levels of society, it is imperative that all of these stakeholders have access to timely and credible environmental information and assessment, and the opportunity to contribute their expertise and information.

SOE Reporting is designed to provide Canadians with careful, objective analysis and interpretation of data which will identify significant conditions and trends in the environment. Of equal importance are the explanations for these trends and the actions being undertaken to sustain and enhance the natural environment.

This report is but one brick in the foundation required to build a fuller understanding of the environment and our role in its maintenance. By increasing awareness of the state of our life-support system, we should be stimulated to protect it through better decision-making and management.

If you are interested in obtaining more information on SOE Reporting, please write to:

State of the Environment Reporting
Environment Canada
Ottawa, Ontario
K1A 0H3

From the microcosm in a drop of pond water to the life-sustaining Ecosphere, nothing exists solely in and of itself. Every species on Earth interacts, directly or indirectly, with its environment — with the air, water, land, and biota that surround and sustain it in a single web of life.

In recent decades, however, scientific investigations have revealed that human activities are causing this web to deteriorate. All around the world, a burgeoning human population is consuming resources and discarding wastes at an unprecedented pace and undermining the health of the whole planetary environment. Accelerated rates of deforestation, desertification, soil erosion, depletion of ozone in the outer atmosphere, and global climatic change as well as steadily increasing levels of air and water contaminants are among the many means by which human activities are diminishing the Earth's ability to sustain not only ourselves but many of the millions of other species with whom we share this fragile globe. Less than a generation has passed since we really began to appreciate the gravity of this crisis, but in that short time most signs point to a worsening of the situation. In the words of Gro Harlem Brundtland, chairperson of the United Nations' World Commission on Environment and Development: "If we do not succeed in putting our message of urgency through to today's parents and decision makers, we risk undermining our children's fundamental right to a healthy, life-enhancing environment."

Recognizing that decision-makers need environmental as well as economic data, the World Commission on Environment and Development urged that nations issue reports on the environment that would complement their traditional fiscal policy statements, budgets, and economic development plans. Canada's own National Task Force on Environment and Economy, composed of federal and provincial ministers of the environment, senior business leaders, and representatives from environmental groups and the academic community, also recommended state of the environment reporting as a tool for informed decision-making.

This volume is Canada's second national state of the environment (SOE) report. The first, published in 1986, was largely executed by two individuals, Peter M. Bird of Environment Canada, and David Rapport of Statistics Canada. The second edition of Statistics Canada's compendium of environmental information, entitled *Human activity and the environment*, was released at the same time. This latter publication contained authoritative information about population, the environment, and socioeconomic activity in Canada, presented in a systematic manner relevant to environmental analysis. The third edition of this report was published by Statistics Canada in October 1991. In December 1986, the federal government authorized Environment Canada and Statistics Canada to establish an ongoing SOE reporting system, with support from other government agencies. This decision was followed, in 1988, by passage of the *Canadian Environmental Protection Act,* which made it a legislated requirement for the Government of Canada to "provide information to the people of Canada on the state of the Canadian environment."

Other federal agencies are also reporting to Canadians on environmental matters within their respective spheres of interest. For example, the Department of Forestry in April 1991 released its first annual report on the condition of Canada's forest resources and their contribution to the economy. Health and Welfare Canada plans to release, in spring 1992, a report examining how Canadians are exposed to environmental contaminants, how our health is affected by that exposure, and what is being done, locally, nationally, and internationally, to address such concerns.

In 1988, Quebec became the first province to release its own comprehensive SOE report: *L'environnement au Québec — un premier bilan.* A second report is expected in 1992. Manitoba and Saskatchewan published their first reports in 1991. As they have done in the past, the four Atlantic provinces are working with Environment Canada to produce a third SOE report for the Atlantic region; the first two were published by Environment Canada in 1979 and in 1985.

As early as 1988, Environment Canada, consulting extensively with a 10-member Public Advisory Committee representing resource industries, consumers, environmental organizations, and the academic community, began planning a second national report. First, the 1986 report was evaluated. This entailed seven commissioned reviews, a small users' survey, and informal feedback from many sources.

As a result of the evaluation and further consultations it was decided that the report would address four main questions:

- What is happening in Canada's environment?
- Why is it happening?
- Why is it significant?
- What are Canadians doing about it?

Faced with the challenge of making a broad diagnosis of environmental quality across the whole of Canada — an area of nearly 10 million square kilometres — for which a great deal of data (of various degrees of usefulness) existed, the department and the Public Advisory Committee came up with the following organization of contents:

Part I (Chapter 1) deals with perceptions of the environment and the dangers inherent in our tendency to look at the world in terms of human economic models. Part II (Chapters 2–14) explores the state of particular environmental components (air, water, land, and wildlife) and examines the major sectors of human activity (e.g., fisheries, agriculture, forestry, mining) that exploit or influence them. Part III (Chapters 15–20) is made up of six regional case studies. Collectively, these reflect to some extent the range of environmental problems across the country. Part IV (Chapters 21–26) addresses six important environmental issues that are of particular concern to Canadians today, ranging from toxic chemicals to stresses on wildlife habitat. Finally, Part V (Chapter 27) discusses the concept of sustainable development and some of its implications for Canada's future.

This ambitious outline was fleshed out by authors of individual chapters selected on the basis of their knowledge and practical expertise in a particular field of environmental science. Collectively and individually, the authors represent an impressive Canadian resource in themselves. They and the other expert contributors who reviewed and improved drafts were drawn from universities, private consulting firms, environmental organizations, industries, and numerous agencies of the federal and provincial governments. The finished text represents a wealth of individual and institutional expertise.

Not infrequently, as the credits attest, a chapter evolved in such a way that a productive collaboration took place between several major contributors. Under these circumstances, it was inevitable (and healthy) that a variety of points of view should emerge in the submissions of the various authors. A conscious effort has been made to acknowledge these differing perspectives, in the belief that the diversity evident in the end product provides a more balanced overview of the state of Canada's environment. No attempt has been made to assign a "grade" or progress rating to individual topics. In the context of such complex issues and responses, such a device was felt to be overly subjective and simplistic.

The subject matter posed its own difficulties. Ecosystems are intrinsically complex and dynamic and do not lend themselves to quick and easy assessment. The present report was compiled from material from numerous sources. Consequently, there was not always a common standard for making valid comparisons or interpretations. A further complication is the fact that on many environmental questions of global importance, such as climatic change, ozone depletion, or the effects of toxic contaminants on wildlife and humans, expert opinion is seldom unanimous. Studies of a given topic by industry, governments, nongovernment organizations, and academic institutions may differ widely in their objectives, methods, and conclusions. As a result, the selection and interpretation of data and information are difficult to achieve in a balanced, objective way.

Where runs of data on key environmental monitors and indicators were available, this report supplies them (e.g., Canadian energy-related emissions of carbon dioxide, levels of toxic contaminants in seabird eggs, and daily household water use per capita). In other areas, state of the environment reporting has identified gaps and inconsistencies in the available environmental data and information. Where appropriate, such shortcomings have been pointed out in the text. Also, in recent years, an interdisciplinary task force has been identifying a comprehensive array of indicators, and in January 1991, Environment Canada released *A report on Canada's progress towards a national set of environmental indicators*. By 1996, the publication date of the third national report, it is hoped that indicators will have been substantially refined and will serve as a quick reference on national environmental conditions and trends.

Numerous polls conducted throughout the country over the last several years have consistently verified that a great many Canadians who are not trained scientists are nonetheless deeply concerned about the state of their country's environment. Their source of interest may be personal, civic, professional, or commercial, or a combination. In many instances, however, they may be unfamiliar with the language and the concepts of science. The aim of this report, therefore, has been not only to describe environmental issues in a Canadian context, but also to provide nonspecialist readers with a user-friendly guide to significant environmental trends, the relationships between these trends and human activities, and current Canadian responses to environmental deterioration.

A conscientious effort has been made, in writing and in editing, to avoid bureaucratic jargon. Environmental concepts and technical terms have been explained, as seemed appropriate, in the text, a footnote, or the glossary. Abbreviations used for units of measurement are written out in full in a chart near the end of the report. Key information is also presented in several hundred figures, maps, and tables, and the whole is tied together by an index. Each chapter can be read independently, although cross-references between chapters have been provided.

As each chapter developed, progressive drafts were read by staff of SOE and other agencies. After revision, each draft underwent peer review by outside experts and by members of the Public Advisory Committee before going to professional editors for final, stylistic revisions. Authors then had an opportunity to verify and approve the final manuscripts. Copy editing, translation, graphic design, typesetting, and a host of other production tasks also had to be scheduled in such a way as to keep the entire project on target. The end product is a testimonial to the efforts of over a hundred direct participants and a much larger supporting cast.

As a summary of the state of the environment in Canada, this report has limitations. The gaps in data and the differences in interpretation are sufficient that no reader should suppose the analyses published on these pages to be infallible. Infallibility was never the purpose. Rather, the aim has been to help concerned nonspecialists to become better-informed participants in the ongoing public process of evaluation and decision-making that will determine future environmental conditions.

The idea of sustainability recurs throughout this book, sometimes overtly and sometimes as an implied subtext. The remaining years of the 20th century will be vitally important to the health of this planet. Centuries of human activities have set in motion consumptive trends that cannot readily be reversed, and whose outcome cannot easily be predicted. Nevertheless, if we give it the opportunity, the Ecosphere has an enormous capability for self-healing and recovery. The importance of adopting and applying values that will sustain the Earth and its resources is the ultimate message of this report.

A report of this scope and complexity was possible only through the ideas and contributions made by a large number of individuals and agencies.

A great debt is owed to the numerous experts who authored or coauthored the 27 separate chapters. The specific contributions of individuals and organizations are acknowledged at the end of each chapter. The collective scientific knowledge of all these people and their ability to interpret environmental data are the foundation of this assessment of the state of Canada's environment. The involvement of so many people, drawn from across Canada, is a distinguishing and important aspect of this report. The views and contributions of university professors, representatives from the private sector, leaders of environmental groups, and government specialists were sought to provide a balance of perspectives and expertise to ensure that this assessment was national in more than name. Without their knowledge, abilities, patience, and willingness to participate in such assessments, this undertaking would not have been possible.

The Public Advisory Committee on the State of the Environment Reporting was instrumental in shaping the document's conceptual framework and outline. Drawn from resource industries, consumer groups, environmental organizations, and the academic community across Canada, 15 experts have contributed strategic direction to this project since the committee's inception in 1988. Members reviewed a number of manuscripts and provided nearly 40 separate reviews of the chapters. Appreciation is extended to the following past and present members:

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Chair, 1988-89

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Colleagues throughout the federal government, in several provincial and territorial agencies, in the private sector, and in environmental groups made tangible and valuable contributions. In particular, within the federal system, Agriculture Canada, Energy, Mines and Resources Canada, Environment Canada, Fisheries and Oceans, Forestry Canada, Health and Welfare Canada, Indian and Northern Affairs Canada, and Statistics Canada responded to the call to participate in this undertaking. Although there was no shortage of good will, delivering manuscripts of chapters when workloads were already onerous resulted in taxing moments. Valid differences of scientific opinion and procedure arose; consensus was not always achieved. Nevertheless, both the published report and the process of state of the environment reporting have been enriched by exposure to these varied perspectives. To all federal colleagues who contributed in a variety of roles to this endeavour, appreciation is expressed.

To supplement reviews provided by the Public Advisory Committee on State of the Environment Reporting, 60 peer reviews were commissioned from recognized experts from outside the federal government. Reviews by federal employees were even more numerous. Many reviews were provided as a professional courtesy or out of individual commitment to the task. Without exception, this cadre of experts provided constructive comments and additional material that brought further insight and better balance to this book. Thank you to everyone.

The fact that the report is greater than the sum of its parts is due in no small part to the chapter coordinators. To these individuals fell the arduous tasks of devising preliminary tables of contents, hiring experts on contract or working with federal agencies to author the chapters, finalizing the outlines, monitoring progress, providing numerous substantive reviews of drafts at all stages, contributing scientific data and interpretation, identifying and engaging the services of reviewers, ensuring the reviewers' comments were considered and incorporated where possible, arranging for approval of the final manuscript, collaborating with editors and translators, working with graphic specialists to finalize illustrations, proofreading numerous drafts and galleys, checking hundreds of references, and generally keeping the project moving forward. In many cases, chapter coordinators researched and wrote text or devised graphics to enhance the material. The final results reflect in many instances a commitment of several years. For their scientific expertise, management skills, and persistence against all odds, deep appreciation is expressed to the following current or former staff of State of the Environment Reporting:

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Paul Bircham epitomized the strong dedication of individuals to Canada's environment in general, and this project in particular. Paul died on September 25, 1991, before this report was completed, and he is remembered for his enthusiasm and commitment.

To transform 2 000 pages of manuscripts, prepared by nearly three dozen different authors, into a single book was an extremely challenging job. The general editors, Susan Burns, Senior Scientific Editor, Canadian Wildlife Service, Environment Canada (Ottawa), Marla Sheffer, writer/editor (Orleans, Ontario) and Raymonde Lanthier, editor (Repentigny, Quebec) worked with a team of five additional professionals; J. Alexander Burnett, writer/editor (Sackville, New Brunswick), David Francis, Lanark House Communications (Toronto), Patricia Logan, Chief, Scientific and Technical Documents Division, Canadian Wildlife Service, Environment Canada, Judy Lord, writer/editor (Ottawa), and Harry Thurston, writer/editor (Amherst, Nova Scotia), all well-known for their expertise in environmental matters. The St. Lawrence chapter was translated by Dialangue Inc. (Quebec). Together, these talented people transformed 27 drafts into language and style appropriate for the audience of nonscientists. Keeping the scientific integrity of the drafts while ensuring a user-friendly style was difficult and required constant liaison with authors and chapter coordinators. The iterative process was time-consuming and arduous. Our sincere appreciation to these people who rewrote, edited, and copyedited numerous drafts and galleys.

The word "support" is inadequate to acknowledge the professionals who accomplished the day-to-day word-processing and secretarial tasks so essential to this report. Over the duration of this demanding project, the manuscripts and related correspondence were transcribed by Odette Leblanc, Marlene Nontell, Martyne Guindon, Carole Lafleur, Susanna Erasmo, Françoise Obissier, Lynda Gravel, and Donald Béland. To these tireless people, who accommodated infinite changes with incredible patience, our gratitude is expressed.

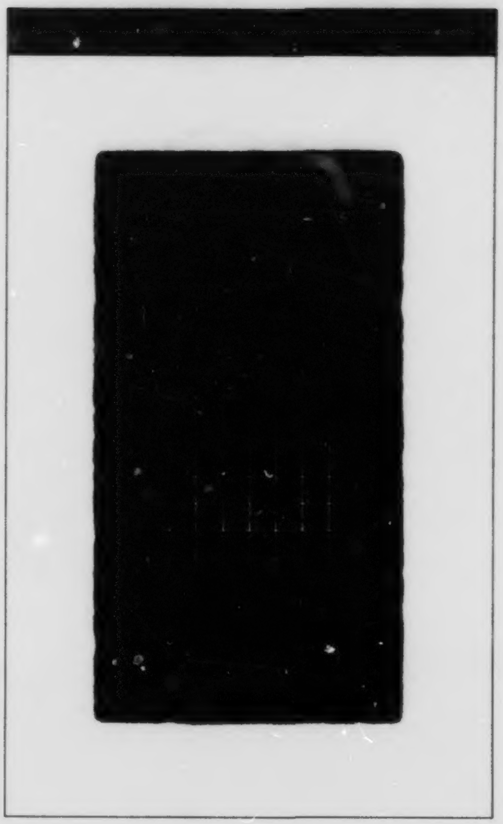
The transformation of over 400 draft illustrations into professional-quality figures has made it possible to portray complicated environmental trend information. Nicole Cardinal coordinated the preparation of figures by Neil Guy, Louise Lachapelle, Yvan Laframboise, Raymond Ménard, Liliane Primeau, and Jean-Marie Viau. The maps were produced by a team, including Daniel Burroughs and Sylvain Hotte, led by Nicole Chartrand and Mike Comeau. In this graphics field, the support of V. Neimanis, Chief, Environmental Information Systems, was most helpful. These creative and hard-working individuals in State of the Environment Reporting were responsible for transforming complex data sets into useful information through their cartographic and computer expertise.

We are indebted to Aurèle Ouimet (Aylmer), Bernard Patenaude, and Lucile Ouimet-Patenaude (Hull) for compiling the index, a very useful element of the report. Likewise, the glossary prepared by Gary Ironside is also meant to assist readers in understanding environmental terms.

Technical production was accomplished in collaboration with Canada Communication Group (Ottawa), copublishers of this report, under the project manager Jean Lalonde. The high technical standards of this publication are due to the skills and commitment of two commercial firms. Banfield-Seguin Ltd. (Ottawa) created the original design and completed the typesetting and final camera-ready artwork under extremely tight deadlines. DW Friesen & Sons Ltd. (Altona, Manitoba) printed a high quality book in a very short time frame, in keeping with their well-earned reputation.

Responsibility for leadership to oversee this project, from inception to publication, was Environment Canada's. Originally, in 1986, the Environmental Interpretation Division, under its Chief, Dr. Peter Rodgers, and National Coordinator, Darrell Piekarz, was responsible for initiating the 1991 report. For the last three and one-half years, responsibility to realize the preparation and production of *The State of Canada's Environment - 1991* fell to Paul Quinn (National Coordinator) and Jean Séguin (Production Manager), under Wendy Simpson-Lewis (Chief, Environmental Analyses and Reporting Division). Working as a team, their understanding of the environment, project management skills, ability to work cooperatively, even temperaments, and tenacity saw the report through difficult times.

Ultimately, however, the task was accomplished because of the commitment of old colleagues and new partners to a shared goal: to prepare for Canadians an assessment of the country's environment. It is hoped that the knowledge gained and partnerships forged will prove useful in working toward a healthy and sustainable environment.



PART
I
PERSPECTIVES

1

COURTESY OF U.S. NATIONAL AERONAUTICS AND SPACE ADMINISTRATION. ENHANCED BY ATMOSPHERIC ENVIRONMENT SERVICE, DOWNSVIEW

HIGHLIGHTS

People have traditionally tended to view air, water, land, other organisms, and themselves as separate components that could each be understood in isolation from the whole. The term "Ecosphere" is meant to suggest an integrated concept of a planet — a unity that includes both humans and the environment.

■

The Ecosphere is undergoing many modifications. In Canada, our forests and grasslands are undergoing various changes; our lakes, rivers, and oceans are being modified owing to increasing numbers of recreational, environmental, and economic interests; our atmosphere is being altered by human and industrial activities; and our productive soils are being used extensively.

■

Today, Canadians as well as many other people throughout the world have increasingly recognized how closely interlinked human, environmental, and economic activities are. Recognition of this ecosystem context has been the basis of international initiatives to promote sustainable development.

■

A sustainable development approach supports the view that a healthy environment is essential for a sound and prosperous economy. Society, economics, and the environment are, therefore, essential as elements of a mutually supporting ecosystem at present and in the future.

■

In Canada, scientists and specialists have contributed to the development of an Ecological Classification System that is designed to suit the needs of those who seek to understand and manage overall ecosystems, rather than single environmental characteristics (e.g., trees, wildlife). The system consists of tiers of ecosystems, from continental-scale ecozones through to site-specific ecoelements.

■

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“

We travel together, passengers on a little space ship, dependent on its vulnerable supplies of air and soil... preserved from annihilation only by the care, the work, and I will say the love, we give our fragile craft.

”

— Adlai Stevenson, *in* Fabun (1967)

INTRODUCTION

The wealth of nations is drawn from the global environment. The fact that Canada is considered to be among the world's richest countries means that the environment has been treating us very well. We have prospered economically to this point, but have we paid full credit to the source? How are we using, maintaining, and caring for the significant sector of the planet under our political influence and jurisdiction? Are we dipping into the country's ecological capital for short-term gain, bequeathing long-term pain to future generations?

This second state of the environment report for Canada indicates how the world's second largest country is faring. We will examine a variety of activities that have weighed upon environmental resources and ecosystems, asking what consequences human decisions and developments are having or are likely to have over the long term.

Because of the wide interest in sustainable development and ecosystem approaches, this chapter goes somewhat beyond a normal introduction. In addition to setting the stage for subsequent chapters that deal with many specific aspects of Canada's environment, it explores some of the theories, ideas, and views about “our environment” and highlights a range of considerations that may need to be reviewed so as to understand the complex web of life within which we live — the Ecosphere, as later defined. It is probably beyond our ability to ever fully comprehend, but it seems important to attempt the task. Perhaps in doing so we will further recognize our own limitations and our lack of knowledge of ecological complexities.

What are the ecological connections between our population numbers, our activities, and all other things on the face of the Earth? We share the world's dynamic living-space with millions of species — plants, animals, and microbes — all united in origin from the same star dust, all composed of the same organic building blocks. Compared to other organisms, however, we have become a force so powerful that what we do in our daily lives profoundly affects not only the continent but the whole world. The cleanness of the atmosphere depends on what fuels we burn in our cars and factories. The purity of water, both fresh and salt, depends on what wastes we allow into rivers, lakes, and oceans. The vitality of plants and animals and their nutritive value as food depend in large measure on how we manage and treat soils.

Human welfare itself depends on the health of ecosystems — for the very good reason that our bodies, like our industries, are maintained by constantly taking in and digesting parts of the external world. When the quality of the environment deteriorates, so do we, along with our economies. This simple linkage has often been overlooked, but now its truth is coming home.

Until the middle of this century, people tended to pay little heed to the planet Earth as an ecological unit because they had only an insider's view of it. Looking around from that shortsighted perspective, all things seemed to be separate and unconnected: rocks, soils, trees, animals, people, water, clouds, cities. The world of experience was a world of fragments. Victims of a faulty outlook, we lacked the overall perspective that would have revealed Earth's unity.

“Can't see the forest for the trees” expresses the befuddlement of people lost in the woods. Just so, immersed within some portion of the Earth's surface, we did not entirely grasp its wholeness, its unity. Lacking the wider perspective that would have shown people as parts of nature's larger organization, we invented what seemed a reasonable reality and then set about studying it piece by piece. We named “our environment” according to the conspicuous and useful pieces — air, water, land, forests, farm fields, and all manner of resources — unaware that each is inseparable from the others and from ourselves. We called the totality “our heritage,” not understanding that we were its legacy.

FIGURE 1.1

The Earth as seen from the moon

Seeing images of the Earth from space has given people a new appreciation of the unity of the Ecosphere.

COURTESY OF U.S. NATIONAL AERONAUTICS AND SPACE ADMINISTRATION. ENHANCED BY ATMOSPHERIC ENVIRONMENT SERVICE, DOWNSVIEW

Source: U.S. National Aeronautics and Space Administration.

With the sharp shock of new insight, Mission Apollo's dramatic photos of planet Earth challenged the old outlook. The pictures from space presented a more truthful vision: a new view from the outside showed a dynamically beautiful sphere surfaced with oceans and continents under swirling clouds (Fig. 1.1). That people are parts and partners of a larger enveloping unity was stunningly exposed. What we had possessively named "our environment" was revealed as the whole world: a vibrant system supporting the human species as one kind among many.

Today, the contradictions between the two viewpoints — the old outlook and the new insight — must be harmonized. Each conveys a different idea of who we are, where we are, and what we are doing. Such ideas in turn shape our sense of importance as to what is precious and worth protecting. The myopic view from the inside suggested that people were of primary importance and the environment was relatively valueless. The outside, moon's-eye view suggests that people coexist within a larger reality, the "Ecosphere," a term and concept that merits some explanation in relation to the more common words "environment" and "ecosystem."

Ecosphere, environment, and ecosystem

Almost everyone today recognizes the falseness of the old rhyme, "Sticks and stones can break my bones, but words can never hurt me." Words and their meanings are important because they can lead or mislead our thoughts and actions. New times need *new* words to express fresh thoughts.

Ecosphere combines "ecosystem" and "biosphere" (Cole 1958; Rowe 1961) and refers to the entire global ecosystem that comprises atmosphere, lithosphere, hydrosphere, and biosphere (the latter meaning all the Earth's organisms) as inseparable components. The planetary surface is conceived as a vital integrated system rather than as separate gas, liquid, and solid strata along with their organic contents. The significant idea behind the word "Ecosphere" is its unity from the beginning. The living world is not "made up" of separate building blocks: rock, soil, sediments, water, air, and organisms. Rather, they all evolved *interactively* during the planet's 4.6-billion-year history.

"Environment" is defined by the United Nations Environment Programme as that outer biophysical system in which people and other organisms exist. The term is handy to refer to whatever surrounds and influences organisms as long as we remember that the verbal separation — "organisms" and "environment" — is not a real-world division. "Ecosystem" conveys the integrated reality.

GLOBAL COEVOLUTION

Studying the Earth's history helps us to understand ourselves better, not apart from the Earth's environment but a part of it. Living things, our own lives, are mysterious expressions of the organizing force of the planetary whole. In a sense, the Ecosphere seems to be an extension of ourselves. In telling its history, we are telling our own.

According to cosmologists, the universe came into being 15 billion years ago, but the Earth on whose skin we exist was born a mere 4.6 billion years ago from the eruption of a dying star. Previous cycles of star-making, plus collapse of this star's centre preceding its supernova explosion, fused charged particles to produce the range of atoms and elements from light to heavy that compose the solar system. Wondrously, over unimaginable time, the beauty and intricacy of today's world have grown out of that initial chaos. Within the Ecosphere the results of the diversifying and harmonizing forces of nature — at work since the beginning — are clearly apparent. People are one such result, perhaps somewhat less harmonious than we were meant to be (Mungall and McLaren 1990). In one way or another, from simple building blocks, the creative Ecosphere proceeded to produce and nourish millions of different organisms, all basically related (Fig. 1.2). Our own bodies are the walking proof of life's symbiotic tendencies: congregations of cooperative cells gathered organically together out of minerals, water, and sunlight.

If in a 10-minute video we could see the compressed history of the Earth from its beginning, then the distinctions that we draw between the inorganic and organic, between air, water, soil, bacteria, plants, and animals, between the rest of creation and ourselves might well blur and disappear. The evolving Ecosphere would be seen as a unity whose parts change, diversify, and increase in complexity. This vision of an evolving whole has led various people to the idea of the planet as being a dynamic body (Lovelock 1988).

Consider Earth's atmosphere. All evidence suggests that it has been maintained for millions of years as an unlikely mixture: high in nitrogen plus reactive oxygen and low in carbon dioxide. Oxygen, a gas that so readily combines with other elements, has nevertheless remained stabilized at about 21% for at least the last 200 million years. Over the last 200 years, however, carbon dioxide concentrations in Earth's atmosphere have risen 25% over what they had been for the previous 160 000 years (see Chapter 2). If the trend continues, what will this mean to life?

In considering Earth's history, past stops and starts in the evolutionary process and their probable causes carry important lessons for us. Studies of the fossil record of the last 600 million years indicate at least five major mass extinctions of animals and plants, although some paleontologists have suggested they occur every 25–30 million years. Evidence is accumulating that the causes are cataclysmic shocks from the impacts of extraterrestrial objects, concussions whose effects reverberated through the system with unexpected consequences. Certain organisms, adapted to the normal regimes of climate in the ocean or on land, were unable to survive. Others, more resilient but hitherto less successful, were suddenly offered unexpected opportunities to fill vacated niches (Kaufman and Mallory 1987; Gould 1989).

The mass extinction at the end of the Cretaceous 65 million years ago eliminated many different kinds of organisms, ended the dinosaur dynasty, and probably cleared the way for diversification of the mammals. Had not a large asteroid smashed into the Caribbean region (the suspected terminal event), our human potential might still be unrealized, still locked away in the chromosomes and genes of early mammals: little shrew- and lemur-like animals hiding in the trees and bushes at night to avoid the phenomenally successful dinosaurs. We and our mammalian relatives may be the beneficiaries of this mass extinction, the winners of the most recent draw, not because of any particular virtue but apparently from sheer luck, by being in the right places at the right time.

It can be argued that our intelligence gives us the power to anticipate and prevent. Human evolution is no longer strictly biological, not dependent on changes or mutations in genetic constitution. Rather, it is primarily cultural, dependent on changes in leading ideas and beliefs. The tattered nature of the Earth's cloak — worn threadbare by the ecologically damaging activities of people all around the world — is idea-driven and not just a product of population pressure. Perhaps the important mutations that can make this generation different from the last, that can head off future shocks and prevent mass extinctions, are to be found with thoughtful people and with thoughtful initiatives. Increasingly, new ideas of the kind of people we should be and what on Earth we should be doing are developing, readying themselves to replace the old, outworn, maladapted beliefs.

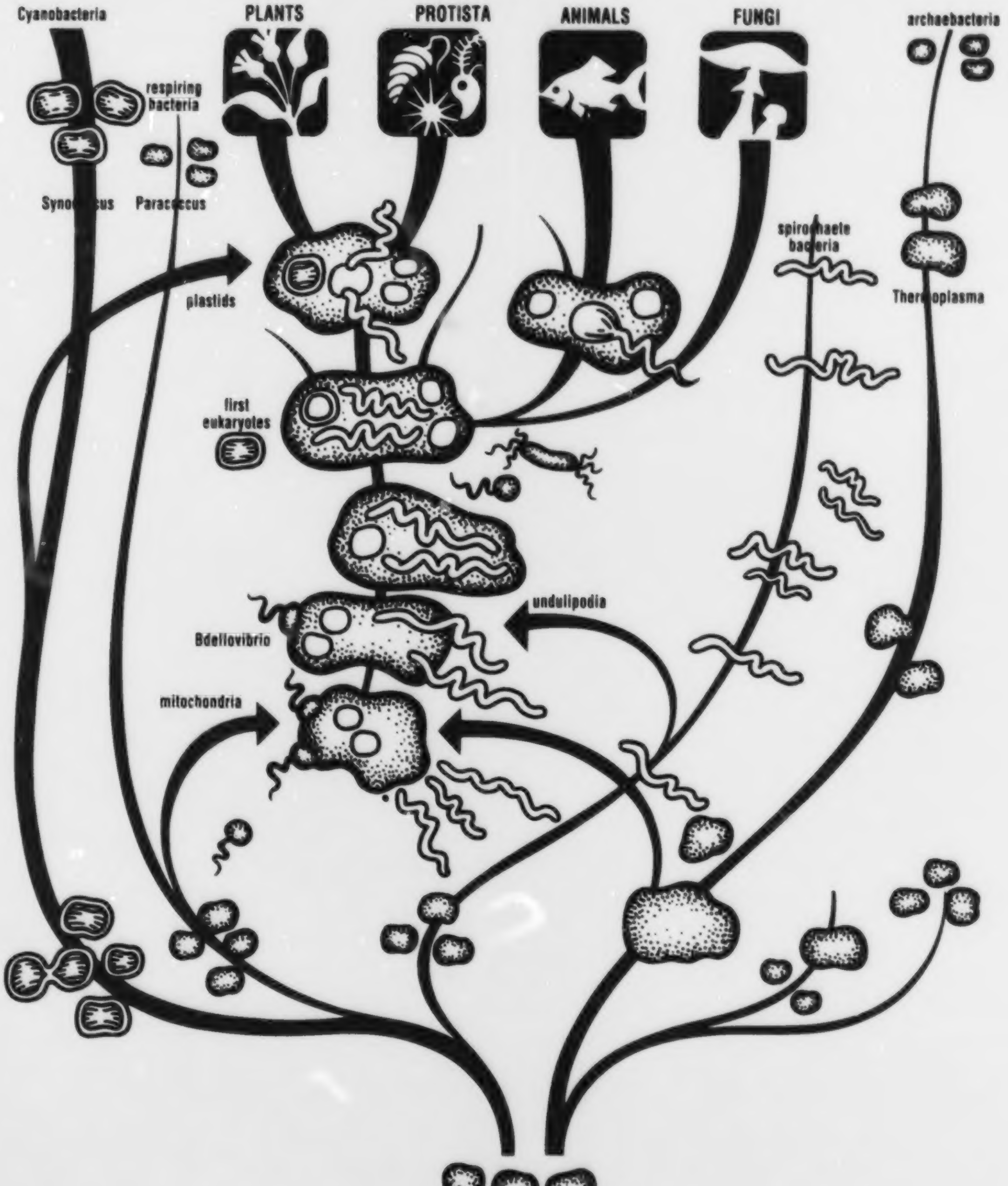
Over the past century, we have managed ecosystems in many different ways. The World Resources Institute (Colby 1990; Mathews 1992) has reviewed these, citing what has been economically and technologically practical, ecologically necessary, and politically feasible. Figure 1.3 as described below is an adaptation of this framework.

Until the middle of this century, the industrialized world tended to see the environment as an infinite supply of resources and a bottomless sink for wastes. This view, often referred to as frontier economics, prevails even today in some developing nations and some sectors of industrialized countries. The economy was seen to exist in almost complete isolation, separate from the environment. Resources were seen as being abundant. So, for example, an increased demand for forest products could be met simply by building a new mill. The more pressing problem with frontier economics was the scarcity of human capital, not of resources. Consequently, the destruction of the environment made little difference, as fresh territory and fresh resources were always within reach. It can also be argued that a further consequence of the frontier economics approach was the development of very narrow, sectoral natural sciences. Government programs, university faculties, and

FIGURE 1.2

The evolution of complex life forms from bacteria

Living things have all evolved from the same simple cells. Although organisms may be grouped into five kingdoms — plants, animals, fungi, Protista (unicellular organisms that show characteristics of both plants and animals), and Monera (bacteria) — for convenience, they also share a common ancestry.


Cyanobacteria
PLANTS
PROTISTA
ANIMALS
FUNGI
archaebacteria
respiring bacteria
Synechococcus
Paracoccus
plastids
spirochaete bacteria
Thermoplasma
first eukaryotes
undulipodia
Bdellovibrio
mitochondria
first prokaryotes
MONERA

Source: Based on a drawing by Laszlo Meszoly.

economic theories all perpetuated this rather unconnected and restrictive outlook on the world. Forests or crops, for example, were never considered in relation to the soil that held them in place, to the rivers that ran through them, or to the animals that lived within them.

More so by the late 1960s and 1970s, many people in industrialized nations began to recognize the interdependence of man and the environment, and they became increasingly concerned about pollution. Although the environment continued to be subjugated to economics, the need to conserve and maintain resource stocks became a consideration for the first time. During this period, policies were introduced to make polluters more accountable for the damage they caused, and the relationship between land, soil, water, air, and animal life was made a factor within the traditional sectoral sciences. Under this "resource management" approach, the environmental implications of resource extraction were assessed to mitigate or limit environmental damage. These assessments, however, were often made as an afterthought, following the planning stages of a given development project. Consequently, business decision-making processes continued largely as before, with environmental consequences considered after the basic decisions were made.

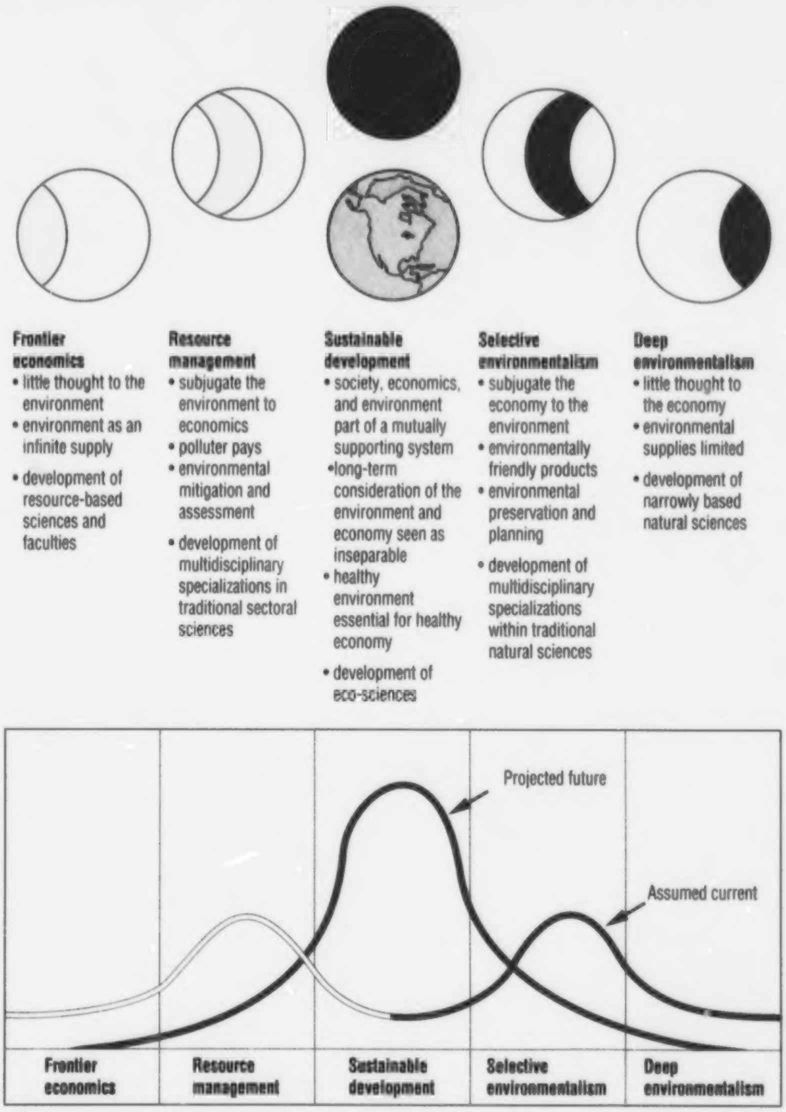
Although resource management remains, to a large extent, the dominant mode of thinking about the environment and economic development, it is becoming clear that environmental awareness is growing at an increasingly rapid pace. "Selective environmentalism" reflects a contrasting style of thinking. It can best be described as a "doing my part" approach, where consumers and agencies express their concerns about environmental degradation by making selected efforts to stop it. This desire to do something for the environment has led to a plethora of "environmentally friendly" products and initiatives, such as municipal blue box programs. However, selective environmentalism places little, if any, emphasis on the economic viability of conservation efforts. Moreover, it makes the assumption that the economy will simply take care of itself.

Deep environmentalism disavows economics to the furthest degree. Here, the human race is seen as no more than one of many species that share this planet. Clearly, deep environmentalism is the antithesis of frontier economics. Where frontier economics gave little attention to the environment, deep ecology gives little attention to the economy, and this is reflected in its approach to science.

The most balanced approach is sustainable development. This outlook supports the view that a healthy envi-

FIGURE 1.3

Conceptual view of five basic forms of environmental management



Frontier economics
- little thought to the environment
- environment as an infinite supply
- development of resource-based sciences and faculties

Resource management
- subjugate the environment to economics
- polluter pays
- environmental mitigation and assessment
- development of multidisciplinary specializations in traditional sectoral sciences

Sustainable development
- society, economics, and environment part of a mutually supporting system
- long-term consideration of the environment and economy seen as inseparable
- healthy environment essential for healthy economy
- development of eco-sciences

Selective environmentalism
- subjugate the economy to the environment
- environmentally friendly products
- environmental preservation and planning
- development of multidisciplinary specializations within traditional natural sciences

Deep environmentalism
- little thought to the economy
- environmental supplies limited
- development of narrowly based natural sciences

Source: J.D.Collinson and E. Wiken, Environment Canada, State of the Environment Reporting, personal communication.

ronment is essential for a sound and prosperous economy. Society, economics, and the environment are, therefore, seen as elements of a mutually supporting ecosystem and are automatically taken into account *before* decisions are made. The sustainable development approach holds that resources must be treated on the basis of their future, as well as their present, value and offers genuine hope of economic development without environmental decline. With today's unprecedented threats of global change and worldwide degradation of environmental resources, the need to integrate environmental, social, and economic goals in the broader ecological context has never been greater. Increased emphasis on "eco-science" logically follows.

GLOBAL PROCESSES AND HUMAN INTERVENTIONS

It is often said that we live in a world sustained by circularities. The way of the universe is to work in endless cycles. The planets and the moon will continue to track their appropriate courses for the next 4 or 5 billion years, and the ocean tides will rhythmically rise and fall. The years and seasons will come and go as the wheel of life continues to turn, bringing death on its downside and rebirth on its upside.

A useful reminder of the connectedness of things is the conception of the world in and around us as systems within systems, from the large to the small, like Russian dolls that fit inside one another. The Ecosphere is the largest system of immediate interest. Nested within it lie the large ecosystems that we distinguish as oceans and continents. Regional ecosystems constitute a lower set within the continents, and still smaller are local ecosystems: a forest, a farm, or a pond.

Such a concept of reality as systems within systems, as different but related levels of organization, is a reminder that parallel processes are present throughout nature, though operating at different scales of size and time. By studying the largest — the Ecosphere — we understand better the importance of keeping our regional ecosystems in good repair. By studying regional-level cycles, we, in turn, begin to understand the Ecosphere.

The phosphorus cycle

Of the six primary nutrients required for plant growth, the one in shortest supply is phosphorus (Kucera 1973; Maxwell *et al.* 1985). It is released from the weathering of rock and volcanic ash into soils, then gradually moved by water erosion to the sea. Incorporated there in bottom sediments, phosphorus awaits the next slow round of uplift or volcanic ejection. Relatively small amounts are rapidly recovered from the ocean at continental edges, due to upwellings from the deep and the deposits on land of seabird guano; however, inland ecosystems must hoard their rock-weathered phosphorus and use it many times, recycling it from soil or lake sediments to plants to animals to the microorganisms of decay and back again.

Sustainable agriculture follows the same model, closing the local cycles by returning manure, sewage, and other wastes to the land. But in industrial countries like ours, the usual procedure is to replace phosphorus lost to erosion and to chemical binding in the soil, or taken up by crops, with phosphate mined from sedimentary rock deposits.

Unfortunately, rock phosphate is a limited nonrenewable resource, distributed unevenly around the globe. Some nations with the largest populations have limited supplies of it. Should the mined-phosphate subsidies to agricultural soils run low in the future, there is some concern that it may be difficult to support the planet's growing population on the limitations of agricultural soils.

The water cycle

Compared to the phosphorus cycle, the hydrologic cycle is more conspicuous and better understood. Water is the lifeblood of the planet, moving ceaselessly in the ocean's swirling gyres and streams, taken up by evaporation into the air to be precipitated on sea and land. Through its movement in the liquid state, water redistributes solar energy from the tropics to the poles, wears away the continents, and dissolves and recycles minerals. As vapour in the air, it is both greenhouse gas and cloud former, regulating global temperatures. It is the dissolving and transporting medium by which all ecosystems and organisms are maintained in health and productivity.

The rapid circulation of water and the air-link by which it is transferred from ocean basins to the land are characteristics not shared by the phosphorus cycle. Water's mobility allows people to intrude in a multitude of ways on the hydrologic cycle (see Chapters 3 and 4). We can mine nonreplenishable water stored deep in the ground and divert the flow of rivers for hydroelectric power, irrigation, or municipal use. We can change the melting regimes of glaciers and polar ice caps by adding to the normal amounts of greenhouse gases. We can affect both evaporation and precipitation by changing the Earth's vegetation cover through deforestation and agricultural land-use practices. Not all these interventions are necessarily bad, but few are done with full understanding of the ecological consequences locally, regionally, and globally.

Certain of our traditional interventions, assumed to be natural and nondisturbing, are now known to affect the water cycle. One simple example concerns the effects of cutting trees, particularly the complete clearing of extensive tracts for replacement by pasture or agricultural crops. That such large-scale deforestation may lead to loss of biodiversity is fairly evident. Less evident is the massive contribution to the carbon dioxide load in the air. Furthermore, destruction of large areas of the forest can change regional climates. Removal of the canopy heat trap so that more radiation is reflected back to the sky may cause a cooling of climate. Removal of the "tree-wick" effect — an important stage in the transfer of water from soil to air — results in a warmer, drier climate. A more widespread effect of deforestation, also related to the "tree-wick" effect, is the likely decrease in atmospheric cloudiness, thereby modifying the global heat balance.

Cycles and resources

One way to evaluate our interventions in Earth's cycles is to consider, in terms of renewability and replenishability, the resources we use for energy, food, clothing, shelter, and other domestic and industrial products. They are derived from two sources: (1) the Ecosphere's air, soil, water, and organisms, including people; and (2) the subterranean areas beneath soils and water. Renewable and replenishable types of resources occur as regular, "normal" parts of ecosystems, whereas nonrenewable and nonreplenishable types are derived from the underlying crust.

1. ***Renewable resources,*** strictly speaking, are organisms and their products. They constitute the only resources that can, by reproduction and growth, actually increase in quantity. These are microorganisms, plants, animals, and humans, reproducing and growing by appropriating from their ecosystems the materials and energy required for their well-being.

2. ***Replenishable resources*** are nonorganic. They make up the matrix of ecosystems: the air, water, soil, and climate (including solar radiation) that envelop and support organisms. The components of the matrix are replenished and maintained by relatively rapid flows and cycles that vary according to geographic location. Radiant energy returns daily, precipitation falls at seasonal intervals, whereas the reconstitution of soils may take centuries. By their quantity and quality in each area, the replenishables support and set the limits of productivity of the renewables — except where humans intervene with special transfers of nonrenewable and nonreplenishable resources (for example, bringing potash or phosphate fertilizer to agricultural fields to increase productivity).

3. ***Nonrenewable resources*** are energy sources concentrated below the Earth's surface, chiefly fossil fuels and radioactive elements. Once used they are gone, their energy content degraded to waste heat and other by-products. Today's economic development is largely based on fossil fuels. They enhance renewable resource productivity in agriculture, forestry, and fisheries, they power industry and energize the built environments of farms, towns, and cities. Use of nonrenewable resources releases waste residues and waste heat, impacting in various ways on renewable and replenishable resources.

4. ***Nonreplenishable resources*** are also crustal materials — bodies of metallic ores and industrial minerals. Once converted into marketable products and dispersed through commerce, they are essentially unavailable for further use, unless gathered and recycled by human intervention using energy. Like the nonrenewables, many are basic materials for goods as well as potent sources of pollutants and toxics: both a blessing and a curse. When products made from these resources are discarded, they contribute to the accumulating volumes of wastes.

This four-part classification is useful in distinguishing the "friendly" from the "unfriendly" things that we use. The ancients were right in naming as the essential elements the replenishable sources of life: earth, air, fire, and water. In comparison, many nonrenewable and nonreplenishable resources can be harmful to life's cycles because of their strangeness; Earth's ecosystems have mostly evolved with only episodic or weak exposure to them. Plants and animals, fresh water and fresh air, humus and humans contain only minuscule amounts of heavy metals, sulphurous minerals, radionuclides, and petroleum's long-chain hydrocarbons, for the simple reason that such substances have been uncommon in the surface life-space. When unthinkingly introduced into the cycles that renew and replenish, they pose particularly hazardous threats to the functional health of the Ecosphere. Out of control, they and their by-products are the causes of acidic deposition, ozone holes, greenhouse warming, toxics in food, and the general pollution of water, air, and soil.

Ecosystem malfunctions or "environmental problems" are really people/resource problems arising from two sources. The first is excessive human demands on regional and local ecosystems, leading to overuse of *renewable resources* beyond their reproductive capacities (as in rundown forests and pastures) and the overuse of *replenishable resources* (air, water, and soil) beyond their restorative capacities. The second is the domestic and industrial use and large-scale release of the nonrenewable and nonreplenishable *subterranean resources* and their by-products: those substances that stress the health of regional and local ecosystems, reducing their renewing and restoring abilities.

Solutions are complex, not simple and neat. They lie in deeper understanding of ecosystems and of what constitutes a healthy world.

CANADA AND GLOBAL GOALS

Canada is a large country, covering 13 million square kilometres of land and water. Notably, it is a high-latitude country, dominated by arctic, subarctic, and boreal ecosystems — the reflection of short growing seasons and rigorous climatic regimes. In summer, the polar air mass retreats so that its southern edge — the cold arctic front — lies near the subarctic tree line, but in winter it advances to cover most of the country. Just beyond its fluctuating edge, huddled close to the warmer United States, the major population centres are concentrated in the temperate forest belts of the east and the west.

The northernness of Canada is the distinguishing national feature. The country's population is concentrated in the south because so much of the northern land mass is marginal for human habitation, and this has left large areas in nature's hands. The extensive wilderness aspect of the hinterlands has become a part of our national psyche. It keeps alive the popular demand for more protected areas: ecological reserves, wildlife sanctuaries, and national parks (see Chapter 7). It is an essential part, too, of Canada's international and domestic tourism.

Despite its seasonally inhospitable climate, Canada is rich in the kinds of resources that foster industrial and commercial development. Forty-five percent of the land mass is capable of supporting forests — equivalent to one-tenth of global forest resources. Nine percent of the world's renewable fresh water moves through its multitude of lakes and rivers. Although less than 7% of the area is productive agricultural land, Canada produces surplus wheat, beef, and other farm products for export to the rest of the world. The same richness is associated with our coastal and inland fisheries. Minerals and energy sources are present in abundance. When Europeans first arrived, the "found" wealth of beaver pelts, lumber, minerals, grazing lands, and rich soils constituted the sole basis of the economy. Today, one-third of working Canadians still derive their incomes directly or indirectly from resource-based industries, cashing cheques written on nature's bank. In the industrial south, caught up in the activities of "value-added" enterprises, it is tempting to conclude that land and water resources are no longer "the engine of industrial growth." Perhaps so, but they are still the fuel without which the economic system would soon run out of steam.

Healthy diverse forests and wildlife, fertile agricultural soils, clear lakes and streams, productive fisheries, minimally polluting energy sources, and the least toxic of the mineral ores will never lose their value in this world, no matter what form future civilizations take.

Therefore, when we frame ecological goals, whether for Canada in a global context or for Canada's major regions in the context of the national whole, our perspective should not be limited to the priorities of the next decade, or the next generation. Rather, they should reflect a sensitivity to perennial ecosystem values that will remain valid for the next 1 000 years and more.

In this regard, the report of the World Commission on Environment and Development (1987) (Brundtland Report) is a useful appraisal of the state of the world and of all its parts. The report points out what is rapidly becoming a truism: that human economic systems depend on and draw their sustenance from the Ecosphere, whose health must therefore be sustained. It explores the prospects for sustaining economic growth in developing and industrial countries and proposes global guidelines for environmental care. The following paragraphs discuss some perceptions on the importance to Canada of three special topics dealt with in the Brundtland Report: energy, technology, and population.

Energy

In a poetic sense "Love makes the world go 'round," but in practice energy does the job. Solar energy, with minor lunar and geothermal energy, infuses the Ecosphere and maintains its ecosystems. Modern societies consume concentrated energy, to power their civilization's built environments, to secure food, clothing, and shelter, to provide transportation, and to maintain industrial enterprises. Affluence and access to energy go hand in hand, and the rich one-quarter of the world's population — Canadians among them — consumes three-quarters of the primary supply. We live in a big, cold country and use much energy for transportation and heating, as well as for the extraction and processing of raw resources for export (see Chapter 12). A publication of Canada's Department of Energy, Mines and Resources states: "Good policy would seem to require that policy-makers recognize that a barrel of oil saved is equivalent to a barrel of new supply, and that demand-side solutions may have cost and environmental advantages over supply alternatives" (Energy, Mines and Resources Canada 1988).

Energy use has significant environmental effects. Acidic deposition and climatic change, the result of nonrenewable energy use, demonstrate the centrality of energy sources and their effects on ecosystem health. A safe and sustainable energy pathway is crucial for a sustained world.

The problem has two sides: how energy is obtained, and how it is used. The safest energy is that which is replenished on short cycles, especially what comes from the sun. Compared to other sources, solar energy produces no waste. It is the norm to which the renewing and replenishing cycles of the natural world are tuned and the standard to which we might at least aspire.

Our dependence on nonrenewable energy poses serious problems. When we mimic cosmic processes in Earth's life-space by obtaining energy from fissioning the heavy unstable elements, the radioactive waste products remain nearby. When we burn coal, oil, and gas, the atmosphere receives volatile hydrocarbons and oxidized carbon, sulphur, and nitrogen — by-products that change the chemistry of the air. The "mineral" energy resources, both gift and curse from the past, have given us a taste for power that drives the search for more. But how much more can the Ecosphere take? Its capacity to absorb the by-products of human energy use sets the limits of global development.

Everything we make and do needs energy. The more we make and do, the more energy we use and the greater the volume of wastes produced. Ecosystems bear the three-way brunt: when energetic materials are extracted, when they are processed, and when their wastes are discarded.

Is there a solution? The Brundtland Report proposes that we follow the "low-energy path" with a twin strategy: reduce society's demands for energy, and get what is required for specific needs from the safest possible sources.

The first part is a call both for efficiency and for a gradual reduction in global energy use. The second part is an ecological challenge: to determine the mix of energy sources that will be least damaging to the Earth's ecosystems over the long term.

Technology and population

There is a view held by some that humanity's chief material link to nature is through technology: the system of ideas and instruments by means of which we take and fabricate what we want from the world. A spin-off from science, technology has until now taken as its goal the serving of humanity's desires for power and information, without considering what the wider effects on environment might be. The Brundtland Report calls for the development of innovative technology with broader goals: sustainability and environmental protection.

All the machines that serve us in one way or another are designed to augment or amplify bodily functions, giving us the abilities to swim to the bottom of the sea, fly at tremendous speed through the air, and tunnel kilometres deep in the earth. Such technology provides the means of cultural evolution, far outstripping old-fashioned biological evolution. The temptation to evolve in ways that increase size and power is technology's chief danger to environment.

Although analogies run the risk of being misleading, it might be said that technology amplifies biological functions. Our bodies require food and drink for growth and energy, and the materials not used are excreted as wastes. In a somewhat similar vein, the same processes hold for the extensions of our bodies: the instruments of technology. Every car, building, or airplane ingests its particular food/drink and generates wastes. But there is one difference. Organic things eat organic foods and produce organic wastes that recycle through the natural stages of bacterial decay and nutrient release and uptake again by plants and animals. Mechanical things, consuming nonrenewable and nonreplenishable resources, release wastes, often in huge amounts, that biological decay cannot handle. Machines swell the energy use of people in industrial countries to many times that of the same population without engines, and so they produce many times as much waste as people, much of it toxic and resistant to breakdown. Consequently, industrial countries generate about 90% of the world's hazardous wastes.

At the helm of numerous kinds of machines, each of us is contributing to the depletion of resources at an accelerating rate and to the production of wastes that interrupt what is basic to our well-being — nature's renewing and replenishing cycles. The loss of biological diversity and the extinction of species (see Chapter 6) largely result from proliferating artifacts that compete with them for space. Global population numbers are dangerously high, but head counts are no longer the heart of the population question. Census figures reporting that Canada has 26 million people are difficult to interpret without bringing in the technological multiplier. To measure the prospects for a sustainable country or world, we may need to gain some sense of the size and environmental impact of each person.

ECOZONES AND HUMAN ACTIVITIES

Canada occupies a significant area of the planet's surface and, from the standpoint of its people, is far too large to be described as a single ecological system. How shall we subdivide the country for the various purposes of study, conservation management, and appreciation? One approach discriminates landscapes and waterscapes as ecosystems, each one broadly comparable to a large terrarium or aquarium containing all the functional organic/inorganic components. These are the basic units of nature, consisting of interacting organisms along with the equally important enclosing matrix of air–water–land. To know that we, like other forms of biota, are maintained by a vital network of ecosystems is the critical truth.

The notion that we should "think globally and then act locally," to conceive the big picture before painting in the detail, is good advice. In a parallel way within the country, understanding Canada's major ecological zones can help to anticipate and illuminate environmental problems within the smaller ecoregions, watersheds, municipalities, and towns. Fifteen ecozones have been recognized within Canada (Wiken 1986), providing a zonation that simplifies the nation's geographic and ecological diversity while providing a framework for examining environmental conditions and trends (Fig. 1.4 and Box 1.1). Brief reference to half a dozen of the ecozones conveys a flavour of the country's ecological variety and provides a foreword to the regional case studies (see Chapters 15–20) presented in this report.

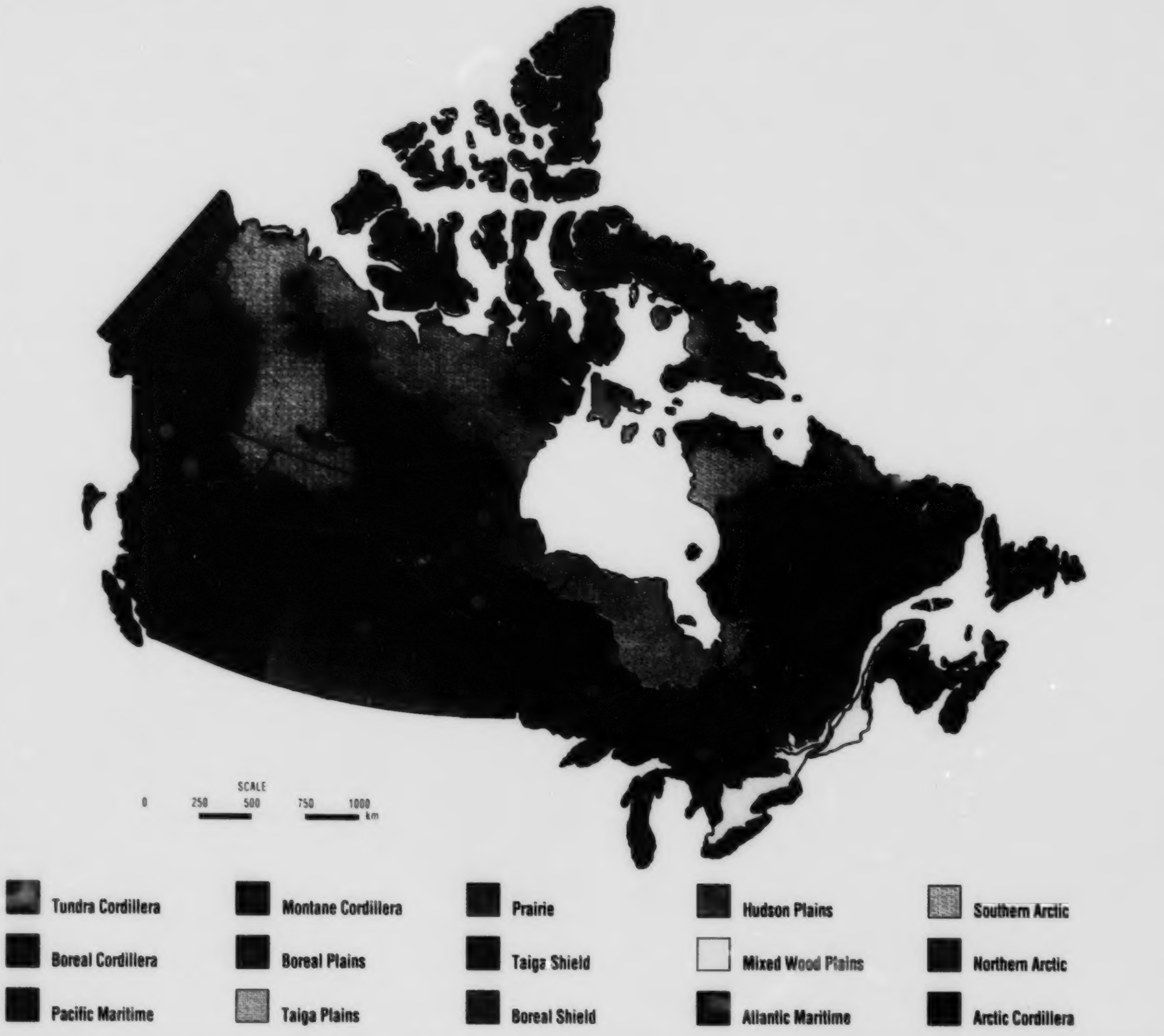
The Northern Arctic

The Northern Arctic ecozone comprises most of the nonmountainous arctic islands plus portions of northeastern Keewatin and northern Quebec. The terrain is predominantly low plateaus and hills covered with glacial moraine, with frequent rock outcrops and marine deposits. The climate is dry and very cold — the average number of frost-free days is about 20 — and continuous permafrost is present at shallow depths below the weakly developed soils. Important terrestrial animals are caribou, muskox, wolf, and polar bear, and, in the sea, walrus, seals, narwhal, and beluga (white whales). Native hunting and trapping, primarily with a marine focus, remain important activities. Much of the sedimentary area is targeted for hydrocarbon development, and one or two mining enterprises are in progress. Climatic change may be felt most dramatically in northern Canada where heating effects are expected to be greatest.

The zone is remote and should be relatively pristine, but it is not. We know now that north-flowing ocean currents carry heavy loads of pollutants that accumulate under the arctic ice. Similarly, pollutants discharged into the

FIGURE 1.4

Ecozones of Canada


SCALE
0
250
500
750
1000
km
Tundra Cordillera
Boreal Cordillera
Pacific Maritime
Montane Cordillera
Boreal Plains
Taiga Plains
Prairie
Taiga Shield
Boreal Shield
Hudson Plains
Mixed Wood Plains
Atlantic Maritime
Southern Arctic
Northern Arctic
Arctic Cordillera

Source: Wiken (1986).

atmosphere by industrialized countries find their final repository in the north, visible before deposition as "arctic haze." Acidic snow, heavy metals, and petrochemical products accumulate in cold-climate ecosystems, vividly illustrating the externally induced problems of maintaining healthy ecosystems in a deteriorating world. The dynamic seas and atmosphere tie all parts of the Ecosphere together, and the innocent frequently bear the brunt of distant carelessness.

The Atlantic and Pacific Maritimes

These two distinctly different coastal ecozones, east and west, share the similarity of maritime climates: adequate dependable rainfall and moderate winter temperatures. Both are forest areas, and the Pacific coast especially is noted for its prosperous forest industry. Mixed agriculture is important along both coasts in the major valleys where fruit and horticultural crops are grown, and where pressures for urban development are frequently strong. The zones are hilly to mountainous, with rivers providing many sources of hydroelectric power. Their natural beauty is a magnet for tourists. Significant industries have to do with shipping and fishing, but all is not well with the latter.

Coastal fisheries are in trouble worldwide. As with many renewable resources, extraction has greatly exceeded the renewal capacity. Also, the productivity of these fishing grounds has inadvertently undergone environmental degradation. We do not really understand the complexity of aquatic or terrestrial ecosystems, and so predictions as to what constitutes sustainable yield and allowable exploitation are largely best guesses, frequently overoptimistic in tone. Particularly difficult is an understanding of the role of environmental deterioration, to which aquatic ecosystems are particularly prone.

Water quality problems begin where people live, on the land, because terrestrial ecosystems and aquatic ecosystems are connected by the hydrologic cycle of evaporation, precipitation, and stream flow. Land use affects the seas through river diversions and coastal discharge, as well as through the practices of agriculture, forestry, city, and industry that produce sediments, organic matter, chemical nutrients, and pollutants that all move seawards.

BOX 1.1

The ecological classification system

Canada's environment has been summarized through several national classification systems. Many of the earliest classifications were designed to address fairly specific objectives or selected resource sectors. The forest regions (Forestry Canada) targeted only the nation's forest resources, the natural regions (Canadian Parks Service) centred on providing a basis for planning, and the physiographic regions (Energy, Mines and Resources Canada) depicted the major physiographic and geological settings of the nation. When environmental resource concerns were much narrower in scope, these classifications were very helpful. But steadily, the concerns within given resource sectors and with the public at large were expanding beyond the single resource itself to the ecological setting that produced that resource. With forestry, for example, interest had broadened beyond just harvesting timber. Wildlife habitat, recreational opportunities, and water and soil degradation had become parallel issues associated with forested areas.

To handle these broader ecosystem concerns throughout Canada, a more comprehensive and multipurpose classification was sought. This led to the development and application of the ecological classification system. It was nurtured by various government agencies, universities, and private industries. The Canada Committee on Ecological Land Classification drew these informal partners together to produce national standards for classification and ecological profiles of the nation. The classification system consists of tiers of ecosystems ranging from the broad scale "ecozones" through to the site-specific "ecoelements." The tiers are hierarchical — the 15 ecozones of Canada can be broken down into 47 ecoprovinces, which can subsequently be subdivided into 177 ecoregions, 5 395 ecodistricts, and so on. These telescoping layers of ecosystems provide resource planners and managers with the versatility to select ecosystem frameworks that suit their particular needs and requirements. Ecosystems are described by a wide range of biological and physical characteristics. The intent was not to bias the classification system to vegetation, to climate, to wildlife, or to any other characteristic. The aim was to establish an unbiased, national ecological information base that would serve many objectives.

The Prairie

The Prairie ecozone of southern Alberta, Saskatchewan, and Manitoba was originally dominated by native grasses. During a century of settlement, its level to gently rolling plains have been converted to cropland and its rougher morainic uplands to rangelands and pasture. It is now a culturally molded landscape, providing much of Canada's cereal and oilseed production. Only fragments of the natural grassland survive, and the larger wildlife species are increasingly rare.

Low precipitation and periodic droughts characterize natural grasslands, and water management is essentially designed to sustain the agricultural goals of the western plains. In some places, the natural precipitation is supplemented by irrigation from rivers that are also drawn upon for municipal and industrial uses, as well as for recreation. Prairie wetlands that play an important role in the hydrologic cycle and as waterfowl habitat have been significantly reduced by ploughing them down in dry years and by draining them in wet years.

Sustainable management of agroecosystems implies a balance between outputs from the soil and inputs to it. What is lost through erosion, leaching, and crop uptake undermines the productive potential of soils. The goal is to maintain this slowly replenishable resource by conserving its ecological diversity and not using its vital constituents faster than they can be reconstituted.

Agriculture's century-long orientation has been to high yields, powered and augmented by various nonrenewable resources. Many farmers recognize the need for soil conservation and the deferred benefits that future generations will derive from it. But meanwhile, until the costs of conservation's future gains are offset in some way, economic survival frequently dictates pursuit of one goal only — high yields. Can sustainability and maximum production coexist? How can the two notions be better integrated and balanced? Chapter 9 further addresses these questions.

The Mixed Wood Plain

Southeastern Quebec and adjacent southern Ontario constitute the largest favourable people-habitat in the country, as evidenced by concentrated population and intensive land use. Proximity to the Great Lakes and the St. Lawrence River is one of this zone's natural advantages. The predominant landforms are level to rolling plains with extensive tracts of productive agricultural soils in a benevolent climate. Forests of the northern part are mixtures of evergreen and deciduous trees, and in the south, where most land has been deforested, they were primarily deciduous. Although urban and industrial pressures on land, water, and air are intense, the broader natural resource problems are not readily apparent, and environmental responsibility is equated with clean, efficient industry.

Where people live close to the resource base, engaged in the primary production of food, wood, or minerals, they tend to conceive environmental problems in terms of resource extraction and depletion. Ask farmers about environmental difficulties and they are likely to mention soil erosion, flooding, weeds, insect pests, and reduced yields. Urban-industrial people have a different perspective. Living where things are fabricated and manufactured, their chief concerns typically are with industrial smog, with the effects of toxic blobs in rivers, with odours from petroleum plants and pulp mills, with safe drinking water and questionable food additives. Because most people now live in urban-industrial areas, their definition of environmental care is usually translated as "cleaning up pollution." The resource base, out of sight except at the summer cottage or in a nature documentary, is commonly out of mind.

A highly industrialized city is an artificially enriched ecosystem that feeds on surrounding or distant ecosystems. Into it flows all manner of wealth that it consumes and metabolizes in various ways: food and drink for its citizens, power and raw resources for its machines. Inevitably, wastes flow out of the city as sewage, industrial effluents, and atmospheric pollutants, all of which affect air, water, soil, and biota of the surrounding regional ecosystems, both terrestrial and aquatic. It might be helpful to change perspective and view urban-industrialized areas not as independent centres but as dependent parts of geographic and ecological regions. Moreover, this could lead us to recognize the need, in the long-term interests of cities, to return some fraction of urban-industrial wealth back to the maintenance, health, and vigour of their hinterlands.

The Boreal Shield and Plains

This large, saddle-shaped area, comprising two ecozones, stretches from Newfoundland to the Yukon, occupying the glacially eroded Precambrian plain. Most soils are shallow and acidic, interspersed with deeper peatlands and occasional tracts of sediments deposited in former glacial lakes. Southward towards the Great Lakes/St. Lawrence River system, the closed-crown forests comprise mixed evergreen and deciduous stands, whereas to the north the conifers dominate.

The zone is marginal for agriculture, and the principal economic activities are mining, hunting, trapping, recreation, and especially forestry. Logging for the pulp and paper industries is prominent, and flights over almost any section show a patchwork of clear-cut areas. Environmental problems at mill sites are those of effluent discharges into water, air, and landfill, while problems in the forest are those of maintaining a diverse renewable resource — the forestland ecosystem.

On this continent, agriculture, unlike forestry, has traditionally had two branches: growing domesticated crops and raising domesticated animals. In western North America, the second branch has depended on unploughed rangelands, and so a science and practice of managing natural grasslands as distinct from tilled and planted croplands have developed. The conceptual difference might be of some value in some cases in forestry, where wildlife and recreation often have been secondary values. Historically, forest managers have often taken an agronomic view of forests: as trees to be cropped, not as complex ecosystems to be maintained. Unwittingly, perhaps, forest management has drifted towards "till-agriculture," towards tree farming and plantation monoculture, using fertilizers to enhance growth of tree cultivars and biocides to discourage competing plants and hungry insects. The "range management" side that contrastingly emphasizes maintaining forest ecosystems intact has gained increased recognition. It places greater emphasis on the conservation of natural diversity within landscapes and the maintenance of integrity of landforms, soils, and noncommercial biota.

CONSERVATION

Following the publication of the Brundtland Report and the government's endorsement of it, various jurisdictions — municipal, provincial, and federal — began devising conservation strategies as a means of achieving sustainable development. The World Conservation Strategy (International Union for Conservation of Nature and Natural Resources 1980) lists three strategic objectives:

1. Maintaining essential ecological processes and life-support systems

The words "life" and "organisms" are often used interchangeably, but the logic of ecology shows this is wrong. Because organisms are inseparable from the environments that sustain them, life must be a function of the two together and their ecological processes. How long would each of us remain "alive" deprived of air, water, atmospheric pressure, and sunlight, deprived of the cycles by which these necessities are replenished, and without the infrastructure of other animals, plants, and microbes? The care that we extend to land, water, and air is fundamental to life protection.

2. Preserving genetic diversity

Saving genetic material is one of the most serious issues facing countries everywhere (see Chapters 6–10). From the tropics to the Arctic, each drastic modification of forests and grasslands, of lakes and seas, deprives organisms in unknown variety and numbers of their natural surroundings. Some of the big ones we attempt to preserve in zoos and botanical gardens, a devaluation of their vital wild roles. The little ones, such as algae, bacteria, and fungi, are mostly unnoticed and ignored. Yet many "backstage" species are more important than the central actors that we see producing foodstuffs and fibre, for they accomplish Goliath feats: the production of oxygen, the fixation of carbon dioxide, the breakdown of wastes for recycling. The genetic diversity we intend to safeguard must be broadly conceived.

3. Ensuring the sustainable use of species and ecosystems

This goal recognizes the necessity of human use along with the first two goals of maintenance and preservation. Humans and their economies are subsystems of the Ecosphere, drawing their resources from it faster and faster. In many parts of the world we are consuming at unsustainable rates, impairing the foundations of future productivity (Rees 1988). Shall we aim to maintain nature's capital and live off the yearly interest, or shall we dip into the capital with the prospect of sooner or later "going broke"?

The three objectives of the World Conservation Strategy are laudable, with great practical value, but they will not be easy to achieve. Humanity has not set its sights on them before, so we must feel our way into the future, learning as we go. Getting our bearings straight is the first task.

MENDING OUR ECONOMIC WAYS

The root meaning of economics is "managing the house." Insofar as management and wisdom coincide, economics encourages care of the home so that its inhabitants may also flourish. It may be that the strong ethical sense of early economic thought must be recaptured and merged with environmental ethics. Despite the explosion of knowledge over the last half century, we have not yet been able to develop a system that takes full account of the costs and benefits involved in living within and from the Ecosphere.

At issue are our ideas of capital and of the income it can sustainably produce. To pass on to future generations a world at least as creative and beautiful as the one we now occupy means protecting the natural capital of air, water, soil, forests, fisheries, and all organisms — the basic parts of Earth's ecosystems — while living on the increment that is surplus to that needed to maintain the Earth's renewing/replenishing processes: the income.

Our problem seems centred around the realization that we do not well understand nature's capital, which makes difficult the calculation of how much income we can safely take. We do not know how many insults an ecosystem can absorb and stay healthy, nor what keeps it renewing. The "sustained yields" or allowable incomes that in our ignorance we set are mostly guesstimates. To avoid the deterioration of the capital represented by Canada's lakes, how much pollution should be allowed? How much income should we take out of forests, meaning how much should we leave behind? Instead of worrying about such complex things, we have tended to focus on economic growth, generally accepted as "good" (but at what costs to the depletion of natural capital?), or on unemployment, generally accepted as "bad" (but with what benefits for the preservation of natural capital?). Sustainable development carries with it the notion that we can have growth and employment by relying on the annual increment of natural productivity.

Conventional wisdom tells us that budget deficits are bad, especially when they grow to the point where servicing their costs detracts from education, health services, and other quality programs. Yet what deficits of natural capital have we chalked up, to the detriment of quality of life now and in the future, by intensive single-purpose agriculture, deforestation, and destruction of species, by polluting rivers, lakes, and oceans, by adding to greenhouse gases and to atmospheric ozone depletion? Some deficits are irreversible; the debt can never be repaid. Our great difficulty is in understanding ecosystems well enough to answer these questions with confidence.

We have been lulled into insensitivity with standard economic indicators such as gross national product (GNP) and gross domestic product, forgetting that they measure only short-term benefits to people-in-the-aggregate, to "the economy." How perverse that by such reckoning the *Valdez* oil spill has made a contribution to the GNP, when we know that the negative ecological impact will be felt for decades! Again, we apply discount rates to determine today's value of the benefits over time from investment, and this makes good sense where the life expectancy of a tractor is 10 years or of a pulp mill is 25 years. But what happens when we evaluate an old-growth forest in the same way? High interest rates encourage rapid exploitation of ecosystems because the future is heavily discounted — the present value of an old-growth forest at today's rate is virtually nil in less than 20 years.

Clearly, making sustainability for the Ecosphere the first priority requires new ways of measuring economic progress other than GNP, new ideas of what can reasonably be discounted and at what rates (zero or minus figures?) to sustain natural capital and to avoid ecological deficits. The time may be ripe to revisit the old philosophies concerned with "quality of life" and "peace of mind," rather than continuing the faith in physical growth that avoids the issues of deteriorating nature, population control, and just distribution of wealth. Can more cars compensate for fewer loons serenading sunsets on lonely lakes? What kind of world do we want to pass on to our grandchildren? A lasting economic system will be guided by ecological sustainability and by ideas of equitability both for present and for future generations. One could well argue that this does not mean a stagnant economy; change for the better can still go on in a fixed Earth-space when *quality* rather than *quantity* is the leading goal.

The foregoing, though critical of our past, is written with the belief that we are beginning to understand the world around us in its entirety, rather than as a series of disconnected pieces. The new insight may at first seem terribly complicated, for it does not fit well with the "school of neat thought" where the parts of both nature and the economy were self-contained, compartmentalized, and apparently easily understood. It makes sense, however, in a way that the old scheme never did. The challenge we face is to develop indicators of environmental health and of sustainability that go with economic indicators, so that we see our place and evaluate our activities on the planet better. What makes this all the more fascinating is the knowledge that the Ecosphere is changing anyway, with or without us. A long-term dynamic process well beyond our control is at play as a result of many often small events throughout history — some natural, some not — but each having its own domino-like effects. How well can we read these evolutionary changes, calculate our impacts on them, and set our course in a complementary way?

MANAGING ECOSYSTEMS OR MANAGING OURSELVES?

Institutional obstacles abound. Departments (of major companies, universities, and governments at all levels in all countries) are established to handle parts not wholes, and so even a name like "Department of the Environment" can be misleading. Implicit in such titles is the idea that a single authority can fully serve that part of the Ecosphere occupied by, for example, Canada — without cooperation from all the other agencies. It also seems to suggest that environment can be thought about, understood, and managed in the same single-minded way as finance or perhaps consumer affairs. Such misconceptions hinder the formation of approaches and the execution of programs sensitive to environmental needs. We seem to have a fondness for rushing into single-sector management programs.

Digby McLaren (1990) has warned that the idea of humans "managing the planet" is highly dangerous and responsible for many of the ecological and social problems we face. Being too human-centred in our short-term approach to environmental problems is, ultimately, ecologically unrealistic. It may seem radical to suggest that people and their institutions are not the be-all and end-all of creation. But is not this exactly what the environmental crunch is telling us, that perhaps a little humility is in order? If we cannot take our eyes off ourselves, at least let us recognize that ultimately it is in our own vital interest to live in balance with the Ecosphere.

We are dependent parts of a greater whole and should not seek to dominate and to expropriate it entirely. Already our species — just one among 20 million others — is diverting to its own use in one way or another 40% of the net primary production of terrestrial ecosystems (Vitousek *et al.* 1986). With another doubling of population will we take 80%? Can we take more without sterilizing the world?

The economist and energy-expert E.F. Schumacher (1973) stressed the importance of quality over quantity: "Guard the health, beauty, and permanency of regional land and water ecosystems, and productivity (yield, quantity) will look after itself." Daly and Cobb (1989) make the same point, defining "development" as that which increases the quality of life, as distinct from "growth," which is quantitative. In a fixed-space Earth, sustainable growth is ecologically impossible; only sustainable development is possible, say Daly and Cobb. Quantitative growth beyond the carrying capacity is the enemy of ecosystem health, beauty, and permanency. C.S. Holling (1986), too, has pointed out that our usual management goals of maximum production, increased efficiency, and reduced risk always result in loss of ecosystem resiliency. In the face of surprises, which are bound to occur, nonresilient systems are vulnerable and prone to collapse.

The practical implications are these. To sustain the global environment, the Ecosphere, we must tend those sectors of it under our political control. In them we live and work, and they are the planning units for implementing conserving programs. In practice, sustainability has to be a regional concept, beginning from the premise that landscape and waterscape ecosystems are contributing parts to the regional whole. No tract is immune to outside influences; even large national parks have to be maintained as parts of the larger regions that surround them. Single sustainable farms may not be feasible, but a sustainable agricultural region where materials and energy are traded between farms is certainly possible. Sustainable forestry is possible regionally, as a patterned activity with an orderly sequence of tending and harvesting the mosaic of forestlands. Coastal marine waters must be sustained as large patterned regional ecosystems — rather than bay by bay, inlet by inlet — as the example of the Great Lakes has shown. Towns and cities are set within regional ecosystems on which they draw and to which they can constructively contribute.

WHERE TO GO FROM HERE

There are really no absolute conclusions to be drawn from this chapter. But, by being aware of varied ideas and views, and knowing there are many more equally worthy of reflection, we may open up our minds further to learn what is needed to make decisions and set directions that are environmentally sensitive. It seems to help to view the whole world in the Ecosphere context and to recognize that within it are many smaller and interrelated ecological systems. The ecological zones of Canada as outlined here are generally regarded as a good basis for considering the dynamic ecological processes of which human activities are a part.

Hopefully, this text has captured a variety of thoughts and opened up enough questions to set the stage for the chapters that follow. The remaining chapters contain the best and most up-to-date information that can be drawn together on the state of Canada's environment at this point. Clearly, much more conceptual thinking and scientific exploration are necessary to better understand the intricate workings of ecosystems and their dynamics. This work will continue, carried out by researchers and specialists in many walks of life. But we cannot defer decisions until "perfect knowledge" has been achieved. We make decisions based on the best information we have at the time. This report, with the information in each chapter, is intended to serve as a consolidation of environmental information and to help provide a better context for sustainable development decision-making.

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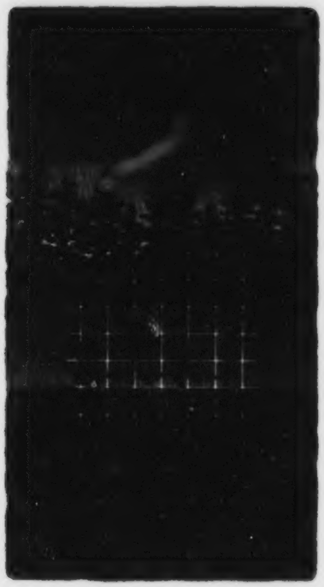
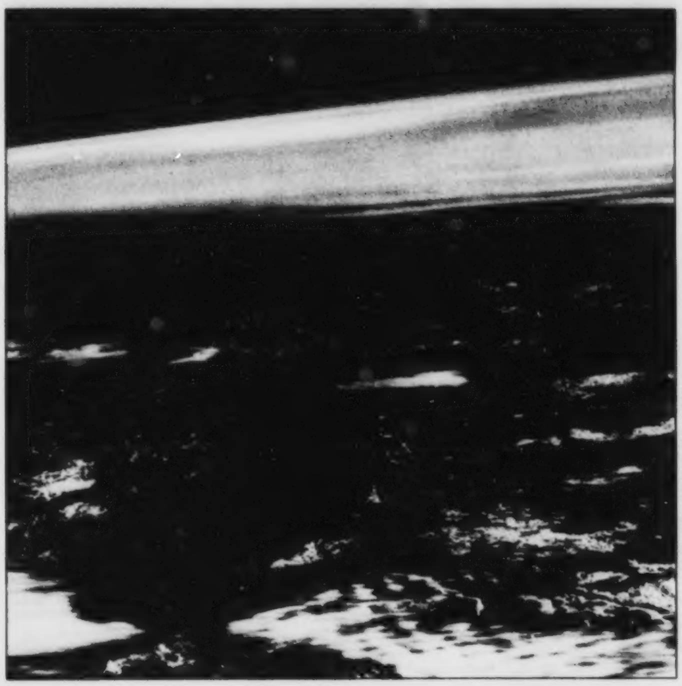


PART
II
ENVIRONMENT AND HUMAN ACTIVITIES

2



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HIGHLIGHTS

Motor vehicles, industrial processes, home heating, garbage incineration, and other human activities introduce contaminants into the air. At the same time, activities such as deforestation reduce the capacity of natural processes to clean the atmosphere.

■

Canada has been a leader in the adoption of controls pertaining to substances, such as CFCs, that lead to the depletion of the ozone layer; however, because of the large accumulation of these substances already in the atmosphere or that could still be released, stratospheric ozone will be threatened for decades to come.

■

The Canadian per capita rate of human-related greenhouse gas emissions is one of the highest in the world. Unless global measures are adopted soon to reduce these emissions, significant warming of the global atmosphere is likely to occur. In Canada, vast areas may experience two to three times the mean global temperature increase.

■

The atmosphere can transport contaminants over long distances, even into the unindustrialized high Arctic, as illustrated by the brown smog known as "arctic haze."

■

Within Canada, considerable progress has been made in cutting back releases of sulphur dioxide, which acidifies soils and lakes and damages plant and animal life. Sulphur emissions are being cut back through joint federal–provincial measures and initiatives on the part of industry. Recently adopted U.S. legislation should eventually result in reductions in the U.S. contribution to Canada's "acid rain" problems.

■

The National Air Pollution Surveillance Network provides a nationwide data base for assessing air quality in Canada's major urban centres. The network routinely monitors airborne particulates (including lead), carbon monoxide, sulphur dioxide, nitrogen dioxide, and ground-level ozone. Annual concentrations of most of these contaminants have decreased markedly over the past 15 years and are now consistently below maximum acceptable levels. The only regularly monitored contaminant that consistently exceeds the maximum acceptable level is ground-level ozone, elevated concentrations of which can retard the growth of farm crops and damage people's lungs.

■

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> **For the first time in my life, I saw the horizon as a curved line. It was accentuated by a thin seam of dark blue light — our atmosphere. Obviously, this was not the 'ocean' of air I had been told it was so many times in my life. I was terrified by its fragile appearance.**
>
> — Ulf Merbold, West German space shuttle astronaut, *in* Lyman *et al.* (1990)

INTRODUCTION

As we come to know more about the solar system and the universe beyond, we become increasingly aware that this world is a rare and possibly unique oasis of life in the midst of a vast cosmic desert. There are many reasons why Earth alone and no other known planet should be populated by living things, but one of the most crucial is that Earth has an atmosphere that is capable of supporting complex life forms as we understand them.

Some three and a half billion years ago, photosynthesizing algae first added free oxygen to the mix of gases enveloping the Earth. Since then, a complex interdependence has existed between the atmosphere and other components of the Ecosphere. Because of this, changes in one of these components almost inevitably induce corresponding adjustments in the others. Life on Earth is sensitive to alterations in atmospheric conditions, and though these changes have never been great enough to eradicate all life, they have often determined the survival or extinction of many individual organisms and species.

In recent years, we have begun to understand how the atmosphere functions and how processes within it affect life on Earth. At the same time, we have also come to realize that human activities are beginning to alter these processes decisively and dramatically. These changes are certain to have some effect on the rest of the Ecosphere, but just how much is not yet clear. If the changes are small and gradual, ecosystems may adapt with relative ease. If they are large and rapid, however, Earth's ecosystems could be exposed to severe and unprecedented stresses, and these in turn could present human communities in many parts of the world with colossal challenges of adaptation.

This chapter considers the problems of atmospheric change facing us today. What is the nature of the atmosphere and how is it being changed? How are we contributing to these changes? How are we affected by them? And how can we respond to the demands they create?

THE ATMOSPHERE: WHAT IT IS AND WHAT IT DOES

The composition and structure of the atmosphere

The atmosphere consists mostly of nitrogen and oxygen, plus small quantities of argon and water vapour and minute amounts of other gases, such as carbon dioxide and ozone. In proportion to the Earth's radius, it is remarkably thin. Eighty percent of its mass lies within its lowest layer, the troposphere, which extends to a seasonally and geographically variable altitude of 6–17 km from the Earth's surface. Another 19% comprises the stratosphere, which continues to about 50 km (Fig. 2.1). The remaining 1% extends outwards for several hundred kilometres, fading gradually into interplanetary space.

How the atmosphere supports life

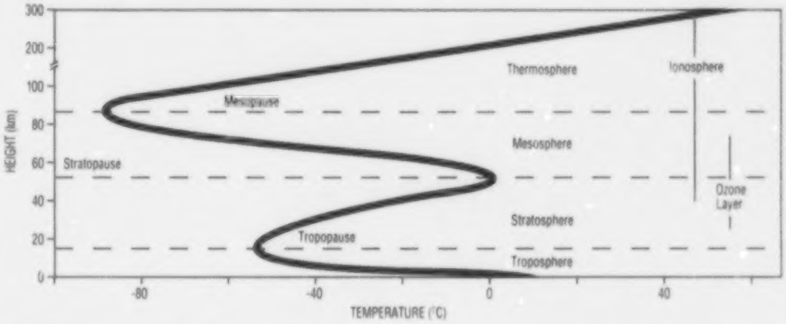
The atmosphere is the Earth's principal reservoir of free oxygen, which is essential, either directly or indirectly, to the metabolic processes of living creatures. It is also a major reservoir of nitrogen and plays a key role in the distribution of carbon and hydrogen. All these elements are basic constituents of most living matter. Living things convert them into the carbohydrates, proteins, and other substances necessary for their existence, and through elimination and decay eventually return them to the environment to be used by other organisms. In effect, the atmosphere is a transient storehouse that facilitates the exchange of essential biochemical ingredients from one life form to another and from one generation to another (Fig. 2.2).

The atmosphere performs a second vital function by shielding living things from both meteorites (which generally incinerate as they travel through the atmosphere) and harmful radiation from space. The predominant radiation hazard to life on Earth is the ultraviolet component of sunlight itself. Ultraviolet rays are the high-energy, invisible wavelengths responsible for common sunburn, but they can also cause skin cancers in humans and have a variety of disruptive effects on many other organisms, including agricultural plants and the plankton that are key elements of oceanic food chains.

FIGURE 2.1

The vertical structure and temperature profile of Earth's atmosphere

Ninety-nine percent of the total mass lies within the troposphere and stratosphere. The warm layer with a temperature peak at the stratopause is caused by the absorption of radiation by ozone.



Source: National Aeronautics and Space Administration (1988).

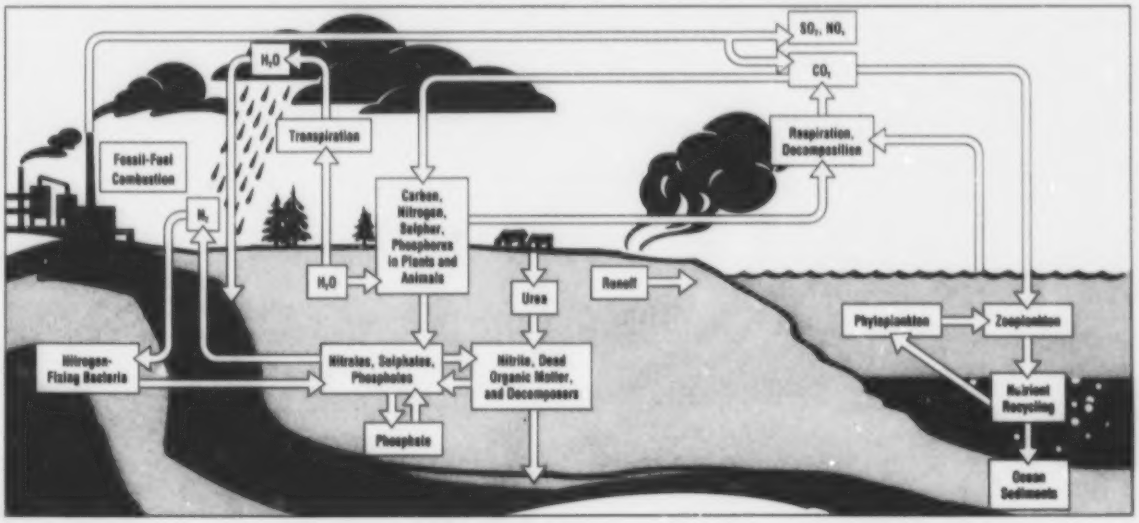
About 8% of the sun's radiated energy is in the ultraviolet part of the spectrum; however, most of the shortest and most harmful ultraviolet wavelengths (known as UV-B and UV-C) are absorbed by stratospheric ozone. Ozone (O_3) is a highly reactive form of oxygen that contains three atoms rather than the more stable two. The "ozone layer," which reaches maximum concentrations at an altitude of 25 or 30 km, is formed when ultraviolet rays break up the molecules of standard oxygen in the stratosphere. (For a detailed explanation of the process, see Chapter 23.) Remarkably, the amount of ozone is small. If the ozone layer were a band of pure gas surrounding the globe at sea level pressure and temperature, it would be no more than 3 mm thick, or about the thickness of three dimes.

The atmosphere supports life in yet another way by maintaining temperatures over most of the Earth's surface within the narrow range to which living things have adapted. Certain constituent gases, present in the atmosphere in minute amounts, cause the atmosphere to act like an insulating blanket around the planet. The gases are known as "greenhouse gases," because they

FIGURE 2.2

The movement of key elements (e.g., carbon, nitrogen, sulphur, and phosphorus) through the Ecosphere

The atmosphere, the most mobile component of the Ecosphere, facilitates exchanges between living and nonliving things, between life forms, and between generations.


SO_2, NO_x
H_2O
CO_2
Transpiration
Fossil-Fuel Combustion
Respiration, Decomposition
N_2
Carbon, Nitrogen, Sulphur, Phosphorus in Plants and Animals
H_2O
Urea
Runoff
Phytoplankton
Zooplankton
Nitrogen-Fixing Bacteria
Nitrates, Sulphates, Phosphates
Nitrite, Dead Organic Matter, and Decomposers
Nutrient Recycling
Phosphate
Ocean Sediments

Note: SO_2 = sulphur dioxide, NO_x = nitrogen oxides, H_2O = water, CO_2 = carbon dioxide, N_2 = nitrogen.
Source: National Aeronautics and Space Administration (1988).

perform much the same function as the glass in a greenhouse, letting in energy from the sun but retarding the loss of energy from the Earth's surface.

The insulating effect is produced primarily by water vapour and carbon dioxide, though other gases such as methane, nitrous oxide, and ozone also contribute to it. These gases compose only a small part of the atmosphere. The amount of water vapour varies, but is never more than 4% of the global atmosphere's volume. Carbon dioxide at present constitutes approximately 0.035% by volume, and the proportion of other greenhouse gases is even smaller. Nevertheless, these small amounts are sufficient to maintain the Earth's temperature at a global average of 15°C. Without them, the Earth's average temperature would plunge to about -18°C, and life as we know it would not exist.

Also of critical importance are the winds and weather. Far more solar energy is received at low latitudes than in polar regions, and this inequality sets the atmosphere in motion. Winds redistribute heat around the globe and bring moisture to the continents, making terrestrial life possible almost everywhere on the planet. This same circulation also redistributes carbon dioxide, methane, pollutants, and so on.

Taken together, these processes shape not only our climate, but our culture. Indeed, in almost every corner of the world, the dress, building styles, recreation, and economic pursuits of the globe's peoples are influenced by the average weather patterns of the regions they inhabit.

Like many environmental mechanisms, however, those of the atmosphere are often delicately balanced and easily disturbed. Indeed, some of the most important mechanisms — the absorption of ultraviolet radiation in the ozone layer and the insulating effect of the greenhouse gases — depend on some of its smallest, and hence most easily altered, components. The atmosphere is not only one of the most important but also one of the most fragile links upon which life on Earth depends.

THE CHANGING ATMOSPHERE

Natural change

Atmospheric change is a natural and continuous process that normally proceeds on geological time scales. The evidence for such change is present in the rocks and soils of the earth, the sediments of the oceans and lakes, and the ice caps of the poles. The rocks and landforms of Canada and other northern lands testify to the impact of the great glaciations, which have covered as much as 30% of the Earth's continental area with ice at various times in the past. A mere 15 000 years ago, almost all of Canada lay under 2 000–4 000 m of ice. Yet the fossil remains of redwood and swamp cedar trees on Axel Heiberg Island suggest that 45 million years ago the high Arctic had a climate similar to that of the southern United States today (Basinger 1986).[1]

For the past 10 000 years, the Earth's climate has approximated that of today (Fig. 2.3). Within more recent times, historical documents provide evidence of fairly frequent climatic fluctuation, but on a much less dramatic scale than the great climatic swings of the geological past. Between the early 15th century and the first half of the 19th, for example, European temperatures averaged as much as 1°C below 20th-century values (Clark 1982).

The scientific collection and monitoring of meteorological data began more than a century ago. Records available for many parts of the world reveal significant fluctuations, locally, regionally, and globally. Across the northern hemisphere, for example, the 1880s stand out as a notoriously cold decade, just as the 1930s and 1980s stand out as exceptionally warm.

How do we account for climatic change? The flow of energy within the atmosphere is in a state of dynamic equilibrium: solar energy entering the atmosphere is balanced over time by energy leaving. If the amount of solar energy entering the atmosphere alters, however, or if the rate at which it moves through the atmosphere changes, the atmosphere adjusts to preserve the balance. Temperatures may change; circulation patterns may alter.

For example, studies of climatic fluctuation suggest that dust and gas from volcanic eruptions may have been a key factor in the fluctuation of weather patterns over the past 400 years (Hammer *et al.* 1980), because these emissions can reduce the amount of solar energy reaching the surface of the Earth. The fluctuations in climate that occur from year to year — or from millennium to millennium — are a part of these and other natural adjustment processes.

The more radical changes associated with the arrival and departure of ice ages, however, require another explanation. Some scientists suggest that recurring changes of this order are related to long-term oscillations in the Earth's orbit and the consequent variations in solar energy received by the Earth (Berger 1977). Although these orbital changes correlate well with many of the climatic variations of the last few million years, the changes in solar radiation are not great enough, by themselves, to account for the very large 5–7°C shift in globally averaged temperature between an ice age and an interglacial period. Some additional process must have amplified the effects, causing a small temperature change to become much greater.

It appears that alterations in the *composition* of the atmosphere — specifically in concentrations of carbon dioxide and methane — may have been a prime factor underlying such dramatic change (Intergovernmental Panel on Climate Change 1990*a*). Researchers have charted concentrations of these greenhouse gases over the past 160 000 years, by an analysis of ice cores from polar ice caps, and found a remarkable correlation between gas

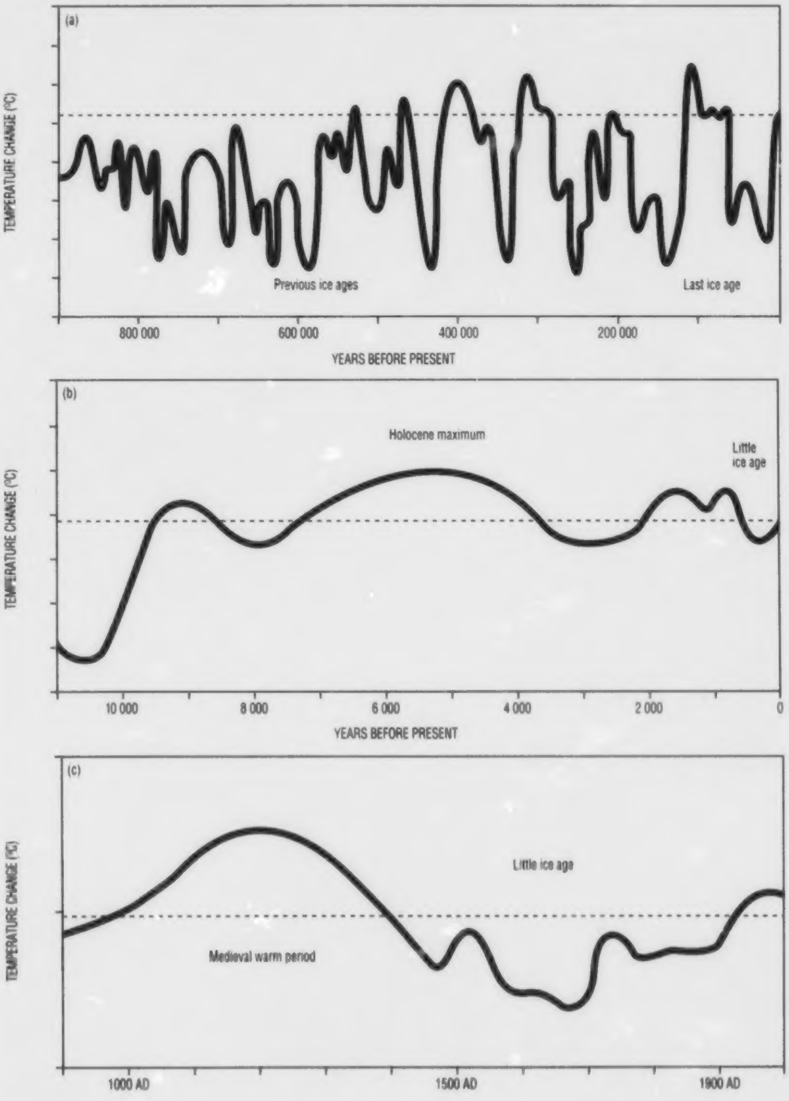
---

[1] Although continental drift has occurred over the past 45 million years, the change in position of the land masses has not been great enough to account for such an extreme change in the climate. For example, Axel Heiberg Island was a few hundred kilometres farther from the North Pole when those forests grew.

[illegible]

A summary of global temperature variations on three time scales: (a) the last 900 000 years, (b) the last 10 000 years, and (c) the last 1 000 years

The dotted line represents conditions near the beginning of the 20th century. Each unit on the vertical axis represents a 1°C change in temperature. For most of the past 900 000 years, average global temperatures were cooler than today. Temperatures have been close to present-day values during the past 10 000 years.



Source: Intergovernmental Panel on Climate Change (1990*b*).

concentrations and prevailing temperatures. Carbon dioxide and methane concentrations in the atmosphere were low when temperatures were low, and high when temperatures were high. (This correlation is illustrated in Chapter 22, Figure 22.1.)

How human activity modifies the atmosphere

Until recent times, atmospheric change has been almost entirely the product of natural forces. Over the last 200 years, however, human activity has begun to play an increasingly significant role in atmospheric change, largely due to two developments: the industrial revolution and unprecedented growth in human population.

The industrial revolution, by applying new forms of energy and organization to economic activity, multiplied human productivity many times and gave human beings greater power to transform the environment than ever before. Through industrialization, the influence of human activity on the environment is now on a scale that rivals the forces of nature.

Apart from greatly increasing the consumption of natural resources, human activity produces large quantities of substances that are toxic or that disrupt natural processes or balances. Some of these substances occur naturally, such as carbon dioxide or sulphur and nitrogen oxides, but they are normally kept at low concentrations by atmospheric dispersal or by conversion into other substances. Human-related outputs of these materials, however, overload natural processes; harmful levels of these substances gradually build up.

The population explosion has compounded the effects of the industrial revolution. World population has risen from perhaps 600 million at the beginning of the 18th century to more than 5 billion today. Increasing demand for natural resources and industrial output has led to the degradation and destruction of vital ecosystems, like the forests, that play a crucial role in atmospheric processes.

Human activities are, in fact, the principal forces behind atmospheric change today — but they are also the forces whose control lies directly in our hands. Changes at the local scale, such as urban smog, are often the most evident. But the scale of some impacts has gone far beyond that, becoming regional and even global in nature.

LOCAL IMPACTS

Our society modifies the atmosphere in two fundamental ways: by changing the face of the land through activities such as deforestation and the construction of built-up areas, and by contaminating the air with pollutants. The former influence is dramatically illustrated on a local scale by the urban heat island effect.

Changing the landscape: urban heat islands

In the process of urbanization, large expanses of asphalt, concrete, and other artificial surfaces are created that contribute substantially to the warming of the city by absorbing and reradiating considerable amounts of solar energy to the air above them. This is compounded by the release of heat from sources such as vehicles and heated buildings. In addition, some airborne contaminants, typically found in higher concentrations in urban environments, directly absorb solar energy and reradiate heat. The net result is that air temperatures in urban areas tend to be somewhat higher than temperatures in the surrounding countryside — the urban "heat island" effect.

Long-term meteorological records from pairs of stations — one within and the other outside a city — show how the effect has intensified with urban growth. Present-day differences can be illustrated by data from two Edmonton weather stations. At the municipal airport, inside the city limits, the mean annual temperature is now about 1.5°C higher than at the international airport, which is located in the countryside some 20 km to the south (Table 2.1).

TABLE 2.1

Urban–rural climate differences at Edmonton, Alberta

Edmonton Municipal Airport is close to downtown, whereas Edmonton International Airport is in an open farming area 20 km to the south. The table shows the difference between the two sites for each measure. Clearly, the urban site is warmer, less sunny, and less inclined to have days of rain, snow, and thunder than is the rural site.

Weather pattern	Municipal airport	International airport
Temperature		
January mean daily minimum	+2.8°C	
July mean daily minimum	+2.6°C	
Annual mean daily	+1.5°C	
Annual heating degree-days[a] (<18°C)		+507
Annual cooling degree-days[b] (>18°C)	+39	
Number of days <-20°C		+15
Number of days <-2°C		+26
Sunshine		
Annual duration (hours)		+51
Precipitation (annual)		
Rain days		+4
Snow days		+2
Thunder days		+5
Number of January hourly observations with:		
Blowing snow		+6
Fog	+49	
Smoke/haze	+20	
Visibility <1 km	+7	
Wind		
Mean January speed (km/h)		+0.4
Mean July speed (km/h)	+2.4	
Percent of calms		+2.8

[a] Heating degree-days are a measure of people's need for space heating.

[b] Cooling degree-days are a measure of people's need for cooling, whether by air conditioning, fans, or other means.

Source: Phillips (1990).

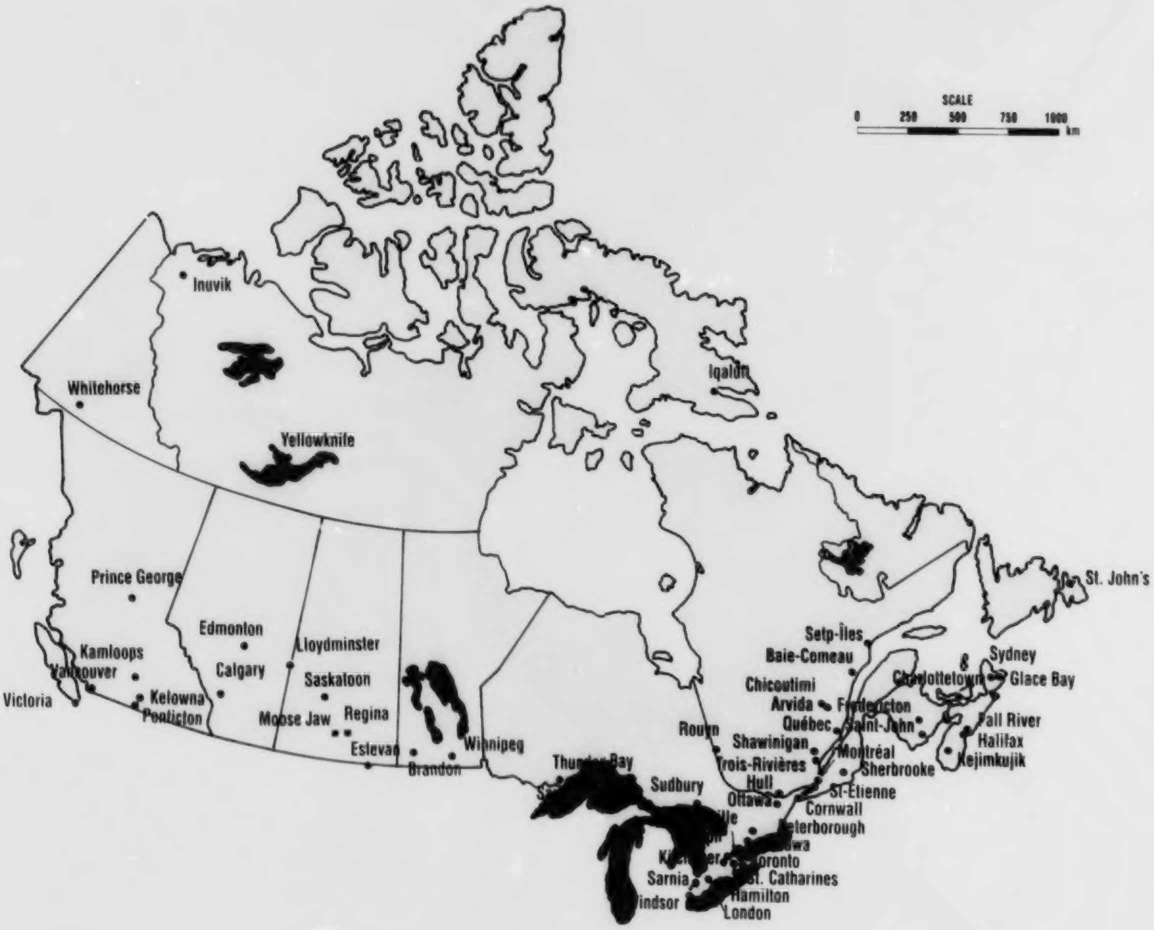
In the winter, the international airport averages 15 more days with temperatures less than -20°C.

Urban effects on local climate can encompass more than air temperature. Tall buildings promote turbulence and the convection of heat above the city. This can lead to increased cloudiness and a greater frequency of precipitation, especially in the summer and downwind of the urban core. Particulate pollutants provide nuclei for the formation of water droplets in clouds, thereby contributing to the phenomenon. In Edmonton, the municipal airport has significantly more hourly observations with visibility restricted by fog, smoke, or haze than the international airport.

Urban heat islands offer some local benefits to city dwellers. Winter heating costs are generally lower in the city centre than in the suburbs or countryside, and city gardeners enjoy the advantages of a longer growing season and fewer chances of an early killing frost. On hot summer days, however, heat discomfort is increased and air conditioning requirements are greater.

FIGURE 2.4

The National Air Pollution Surveillance Network as of 1989


SCALE
0
250
500
750
1000
km
Inuvik
Whitehorse
Yellowknife
Iqaluit
Prince George
Kamloops
Vancouver
Victoria
Kelowna
Penticton
Edmonton
Calgary
Lloydminster
Saskatoon
Moose Jaw
Regina
Estevan
Brandon
Winnipeg
Thunder Bay
Sudbury
Rouyn
Setp-Îles
Baie-Comeau
Chicoutimi
Arvida
Québec
Shawinigan
Trois-Rivières
Hull
Ottawa
Montréal
Sherbrooke
St-Étienne
Cornwall
Peterborough
Oshawa
Toronto
Kitchener
Sarnia
St. Catharines
Hamilton
Windsor
London
Fredericton
Saint-John
Charlottetown
Sydney
Glace Bay
Fall River
Halifax
Kejimkujik
St. John's

Source: Environment Canada (1990*b*).

Contaminating the atmosphere

Factors influencing local air pollution

Local air pollution levels and patterns depend on several factors, notably:

- the physical and chemical characteristics of contaminants,
- the sources of the contaminants,
- local topography, and
- prevailing meteorological conditions.

Urban areas typically experience elevated levels of many atmospheric contaminants. However, significant contamination can also occur in rural areas: pollution may be transported downwind from urban sources or it may be produced locally by large mills, busy highways, and activities such as aerial pesticide spraying. Within a given area, pollution levels may fluctuate considerably during a day or over the course of a year, as emission rates change.

Owing to differences in physical and chemical properties, some contaminants persist longer in the atmosphere than others. Hence, the potential exists for them to travel farther from their sources, affecting larger areas, but in ever-decreasing concentrations.

Contaminants in the atmosphere disperse according to meteorological conditions and topography. Vertical dispersal is sometimes restricted by temperature inversions (warm air overlying cooler ground-level air) that prevent contaminated surface air from mixing with higher-altitude air currents. Topographic barriers that act as windbreaks can further inhibit contaminant dispersal. For example, in the area around Whitehorse, temperature inversions exacerbated by the local mountains frequently lead to severe episodes of woodsmoke pollution during the winter (Pulleyblank and Wile 1988).

Where there are no major topographic barriers, the horizontal dispersal of contaminants is largely dependent on wind speed and direction. If the wind is light or variable, contaminants may accumulate over their source areas. This can happen when the normal eastward progression of weather systems stalls and an air mass remains stationary over a region for several days. On the other hand, higher winds can turn a local pollution problem into a regional one, especially if the wind does not change direction for days on end. In eastern Canada, for example, persistent southerly winds can carry contaminants from major industrial areas such as the Ohio River valley and New York State into southern Ontario, Quebec, and the Maritimes. This adds to the pollution emanating from Canadian sources.

Monitoring local pollution

Substantial amounts of data exist for the common airborne contaminants in Canadian urban areas: suspended particulate matter (including lead and coefficient of haze), sulphur dioxide, nitrogen dioxide, carbon monoxide, and ozone. For other contaminants, and in rural areas, the data are not as extensive or complete. In 1969, the National Air Pollution Surveillance (NAPS) Network was established as a joint project of the federal and provincial governments. As of 1989, the network consisted of about 130 stations, monitoring air quality in over 50 Canadian urban centres (Fig. 2.4), where approximately 70% of Canadians reside. The stations are strategically located in industrial, commercial, and residential areas where air pollution could pose a substantial problem to people and the environment.

BOX 2.1

Canada's air quality objectives

An air quality objective is a target level for a pollutant that affords a specified amount of protection for humans, other life forms, and/or inanimate objects, such as soil and water. In Canada, the federal government sets national ambient air quality objectives (NAAQOs) based on recommendations of the Federal–Provincial Advisory Committee on Air Quality, a committee whose roots extend back to the late 1960s. Provinces can choose to adopt NAAQOs simply as objectives or as enforceable standards within their own jurisdictions.

Canadian NAAQOs are three-tiered (Fig. 2.B1). The "maximum desirable level" set for each pollutant represents the long-term goal for air quality and also provides a basis for an anti-degradation policy in the least polluted parts of the country. The "maximum acceptable level" is intermediate and intended to provide adequate protection against the effects of pollutants on human health and comfort, soil, water, vegetation, animals, materials, and visibility. The "maximum tolerable level" represents a concentration beyond which action is required without delay to protect the health of the general population.

Canada's NAAQOs (Table 2.B1) generally conform with air quality requirements in many other countries. A review of these objectives and the need for objectives for other pollutants is ongoing. Table 2.B2 shows some environmental and health effects of various levels of air quality.

FIGURE 2.B1

Canada's three-tiered system of air quality objectives

High pollutant levels

——————————— maximum tolerable level

Tolerable range of air quality

– – – – – – – – – – – – – – maximum acceptable level

Acceptable range of air quality

——————————— maximum desirable level

Desirable range of air quality

Low pollutant levels

Source: Hilborn and Still (1990).

National ambient air quality objectives (NAAQOs) have been established for the following common pollutants: sulphur dioxide, suspended particulate matter, ozone, carbon monoxide, and nitrogen dioxide (see Box 2.1). The gases are continuously monitored at NAPS sites. The vast amounts of data collected on each contaminant are translated into annual averages and, to reveal short episodes of high concentrations, into (running) averages for 24-hour, 8-hour, and 1-hour periods. Air is also sampled for 24 hours on a six-day cycle and analyzed for total suspended particulate matter, lead, and some other heavy metals, as well as sulphate and nitrate. Some stations in the network also monitor additional pollutants, including toxic organic compounds and metals. To assess national urban air quality trends, this discussion uses the NAPS Network data for the following common pollutants: suspended particulate matter; lead; three major combustion gases — carbon monoxide, sulphur dioxide, and nitrogen dioxide; and ground-level ozone.

TABLE 2.B1

Canada's national objectives regarding ambient air quality

Pollutant	Averaging time	Maximum desirable concentration	Maximum acceptable concentration	Maximum tolerable concentration
Sulphur dioxide	annual	11 ppb	23 ppb	—
	24-hour	57 ppb	115 ppb	306 ppb
	1-hour	172 ppb	344 ppb	—
Suspended particulates	annual	60 µg/m³	70 µg/m³	—
	24-hour	—	120 µg/m³	400 µg/m³
Ozone	annual	—	15 ppb	—
	1-hour	50 ppb	82 ppb	150 ppb
Carbon monoxide	8-hour	5 ppm	13 ppm	17 ppm
	1-hour	13 ppm	31 ppm	—
Nitrogen dioxide	annual	32 ppb	53 ppb	—
	24-hour	—	106 ppb	160 ppb
	1-hour	—	213 ppb	532 ppb

Source: Environment Canada (1990a).

TABLE 2.B2

How Canada's national objectives regarding ambient air quality relate to health and environmental effects

Pollutant	Good range (0 – maximum desirable)	Fair range (maximum desirable – maximum acceptable)	Poor range (maximum acceptable – maximum tolerable)	Very poor range (over the maximum tolerable[a])
Sulphur dioxide	No effects	Increasing injury to species of vegetation	Odorous. Increasing vegetation damage and sensitivity	Increasing sensitivity of patients with asthma and bronchitis
Suspended particulates	No effects	Decreasing visibility	Visibility decreased. Soiling evident	Increasing sensitivity of patients with asthma and bronchitis
Ozone	No effects	Increasing injury to some species of vegetation	Decreasing performance by some athletes exercising heavily	Light exercise produces effect in some patients with chronic pulmonary disease
Carbon monoxide	No effects	No detectable impairment but blood chemistry changing	Increasing cardiovascular symptoms in smokers with heart disease	Increasing cardiovascular symptoms in nonsmokers with heart disease. Some visual impairment
Nitrogen dioxide	No effects	Odorous	Odour and atmospheric discoloration. Increasing bronchial reactivity in asthmatics	Increasing sensitivity of patients with asthma and bronchitis

[a] The upper limit of the very poor range is not defined. At extremely high levels of any of these pollutants, symptoms would be worse than those listed.

Source: Environment Canada (1990a).

Levels of common pollutants in urban areas

Suspended particulate matter

"Suspended particulates" include a wide variety of substances that are in a small enough form to remain airborne for long periods of time. Particulates of natural origin include wind-blown dust, sea salt, smoke from forest fires, pollen, and volcanic ash. Of the human-generated particulates, approximately 50% originates from industrial activities such as mining, quarrying, and pulp and paper operations. Other important sources include thermal power plant and motor vehicle emissions, as well as incineration of industrial and municipal waste and burning of wood waste in forestry operations (Environment Canada 1990*a*).

Inhalable particulates, especially those small enough to be drawn deep into the respiratory tract, have been implicated in human health problems that include reduced pulmonary function and aggravation of existing pulmonary and cardiovascular disease (Ericsson and Camner 1983). Among those at high risk are individuals with chronic obstructive pulmonary disease, asthmatics, and smokers, as well as the elderly and the very young. Other effects of suspended particulates include reduced visibility, soiling through deposition, and the formation of airborne acidic pollutants (acid aerosols).

In Canada, annual average levels of total suspended particulates have been below the maximum acceptable level since 1975 (Fig. 2.5). In absolute terms, they fell by 44% between 1974 and 1989 — an improvement that reflects the cleaner processes adopted by industrial and commercial facilities, the trend toward cleaner energy sources like natural gas, and more frequent street cleaning.

Lead

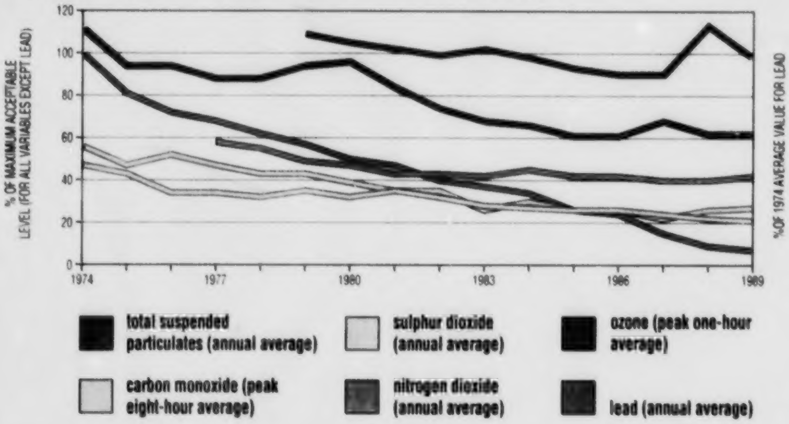
In the atmosphere, lead is the most prevalent of a group of "heavy metals" that include mercury, cadmium, and manganese. Lead is a contaminant of major concern because of the harm it does to many human tissues and organs, especially the nervous system, the kidneys, and the cardiovascular system, and particularly in children (Hilborn and Still 1990). Adverse effects have been observed in some population groups with blood lead levels as low as 10 µg/dL, and some scientists suggest that any level, no matter how small, may be harmful.

FIGURE 2.5

Trends in Canadian air quality, 1974–89

The graph shows yearly average pollutant concentrations for all stations in the NAPS (National Air Pollution Surveillance) Network, as a percentage of the maximum acceptable level of the national ambient air quality objectives for each pollutant, with the exception of lead. Because no objectives have been established for lead, the annual averages have been indexed by setting the 1974 value at 100. For most pollutants, the annual average recorded at the station is shown; however, peak eight-hour and one-hour averages for carbon monoxide and ozone, respectively, are better indicators of the effects of these pollutants.

Average pollutant concentrations in the atmosphere have generally fallen over the last 15 years, with a levelling off of some in recent years. All the pollutant indicators, save ozone, are well within the acceptable level of the air quality objectives. Hot, dry weather in summer 1988 contributed to the high ozone levels recorded that year.



Source: T. Furmanczyk, Environment Canada, personal communication.

Since 1974, concentrations of particulate lead have come down 93% (Fig. 2.5), largely because of the stepwise switch to unleaded fuels. The effective elimination of lead as an additive in automobile gasoline occurred on December 1, 1990, although gas with a low-lead content will still be allowed in activities such as farming, commercial fishing, and trucking, where engine durability is a major concern. Transportation, which accounted for almost two-thirds of national lead emissions in 1982, was responsible for only one-third in 1987. Today, industry is the largest source of lead emissions, particularly mining, milling, and smelting. These sources are usually at a distance from heavily populated areas.

Carbon monoxide

Carbon monoxide (CO) is a colourless, odourless, highly toxic gas, generated when carbon-containing material burns with insufficient oxygen. It occurs naturally in the atmosphere in trace amounts. Approximately 66% of the nation's carbon monoxide emissions are attributable to motor vehicles, especially cars and small trucks. Fuel combustion in stationary sources (e.g., space heating) and industry contribute about 11% together. Locally important sources can include the burning of firewood and wood waste (e.g., burning of wood waste in forestry operations) (see also Chapter 14).

Carbon monoxide reduces the capacity of red blood cells to carry oxygen to body tissues. Oxygen deficiency, with potentially fatal effects, can occur at chronic exposure levels as low as 14 ppm, or at exposures over a few minutes to levels of about 5 000 ppm (Hilborn and Still 1990). People with heart and circulatory system problems, as well as smokers and anemic individuals, are among those at greatest risk.

Peak eight-hour (as opposed to annual average) values for carbon monoxide are displayed in Figure 2.5 because they are a better indicator of the pollutant's effect on health. The network-wide average in 1974 was less than half of the maximum acceptable eight-hour objective, and it fell a further 63% by 1989. Since 1983, at least 90% of the stations have consistently met that objective, and in 1989, only two stations, one in Calgary, the other in Regina, exceeded it (T. Furmanczyk, Environment Canada, personal communication).

Sulphur dioxide

Sulphur dioxide (SO_2) is a colourless gas with a strong pungent odour. Industrial processes account for two-thirds of Canadian emissions, through oil and gas processing and the smelting of sulphur-rich ores. The remaining third is largely from the burning of sulphur-containing coals or heavy oil, particularly in thermal power plants (Environment Canada 1990*a*).

In the atmosphere, sulphur dioxide combines with oxygen and water to form sulphuric acid, the major component of acid rain (see "Acidic deposition: the extent of Canada's problem" in this chapter and Chapter 24 for a full discussion). For humans, exposure to sulphuric acid can lead to reduced lung function and possibly chronic lung disease. Long-term or chronic exposures have been linked to the increased incidence of respiratory diseases such as bronchitis, particularly in young children (Dodge 1983).

From 1974 through 1989, the average annual level of sulphur dioxide for all NAPS sites decreased by over 50%, from a high of just under 60% of the maximum acceptable concentration (Fig. 2.5). This improvement was largely due to the shift away from high-sulphur fuels, industrial process improvements, and more stringent controls of industrial emissions. Over 90% of the stations have been reporting annual means below the maximum acceptable level of 23 ppb, but exceptions do occur in some industrial areas.

Nitrogen oxides

Nitrogen and oxygen together compose 99% of our atmosphere, exclusive of water vapour. They combine to form a variety of gases, through natural processes and phenomena such as bacterial action in the soil, lightning, volcanic activity, and forest fires. Human activities generate nitric oxide primarily through high-temperature combustion. In Canada, about two-thirds of these emissions come from transportation, and most of the rest from fuel combustion in power plants, homes, and commercial and industrial establishments. Of special concern is nitrogen dioxide, which is formed by the oxidation of nitric oxide and contributes to the formation of smog.

Individuals with asthma and bronchitis can experience increased airway sensitivity when nitrogen dioxide levels exceed the one-hour maximum tolerable limit of 532 ppb (Environment Canada 1990*a*). Higher levels of exposure can suppress vegetation growth (Thompson *et al.* 1970; Ashenden and Mansfield 1978), corrode metals, and degrade textile fibres, rubber products, and polyurethanes (National Academy of Sciences 1979).

Between 1977 and 1989, mean annual nitrogen dioxide concentrations declined 32%, but most of the reduction occurred in the first four or five years (Fig. 2.5). The downward trend would have continued, were it not for the steady increase in numbers of vehicles. No individual station has exceeded the annual maximum acceptable level since 1977.

Ground-level ozone

About 90% of the Earth's ozone is found in the stratosphere, where it performs the vital function of absorbing the more harmful wavelengths of ultraviolet radiation from the sun. Low concentrations of naturally occurring ozone are also present in the lower troposphere. Ozone is not directly emitted as a pollutant by human activity. It forms as a secondary pollutant when sunlight drives a reaction in air that is contaminated with volatile organic compounds (VOCs) and nitrogen oxides. High concentrations that exceed the maximum acceptable one-hour objective can build up under the following three conditions: high air temperature accompanied by direct sunlight; the presence of VOCs and nitrogen oxides; and stagnation of air mass movement for several days. In Canada, these conditions are usually met only from May through August in urban or adjacent downwind areas, where vehicle emissions are a prime source of precursor pollutants (see Chapter 13).

In humans, ozone can cause a decrease in pulmonary function. Children's lungs are particularly susceptible to damage (Lippmann *et al.* 1983). Although human health implications seem to be tied to short-term, high-level ozone exposure, vegetation appears to be more susceptible to lower doses over the longer term. Damage to many forms of vegetation has been documented. With average growing season ozone concentrations of 40–50 ppb, some Ontario crops have had yields reduced by up to 12% (Hilborn and Still 1990).

Because of the significance of high, short-term exposures for human health, Figure 2.5 provides peak one-hour values. From 1979 on, the averages of such values have remained close to the maximum acceptable level. Although a general decline occurred from 1979 through 1987, record high ozone levels were recorded in eastern Canada during the abnormally hot weather in summer 1988. At a station in the Toronto suburb of North York, for example, the one-hour maximum acceptable level was exceeded 157 times. If global warming occurs in the coming decades and emissions of VOCs and nitrogen oxides are not reduced, such episodes of high ozone pollution are likely to continue.

Looking ahead

In some respects, the air we breathe in Canada is now cleaner than it was 20 years ago. In part, this is because of federal and provincial programs addressing common pollutants from industrial and transportation sources, and the response of industry to such measures. Other factors have been instrumental, however. Energy crises, coupled with concern over the long-term availability of fossil fuels, have forced our society to explore alternative fuel sources, such as solar energy, and to conserve traditional sources through the development of smaller and more fuel-efficient vehicles and more energy-efficient industrial processes and homes.

Other aspects of local air quality have shown little or no improvement: notably, levels of nitrogen oxides and the secondary pollutant, ozone. Because both nitrogen oxides and VOCs are implicated in the formation of ground-level ozone, an action plan endorsed by the Canadian Council of Ministers of the Environment (1990) addresses ways of reducing emissions.

Finally, many other substances emitted to the atmosphere are not monitored regularly or nationally. The cost of doing so would be prohibitive, and air quality objectives for them are yet to be determined. Though national data collection programs may not be economically possible — or indeed warranted — for many of those substances, more research is necessary if we are to better understand current and potential threats to human health and the environment. (Information on some of these substances can be found in Chapters 13 and 21.)

REGIONAL IMPACTS

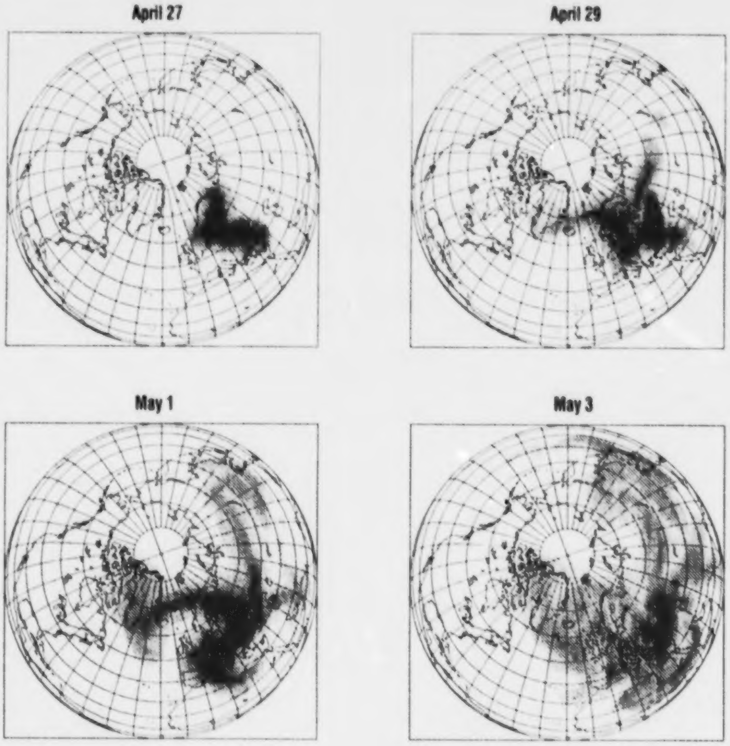
At any given moment, millions of tonnes of solid, liquid, and gaseous matter are being moved around the Earth by the circulation of the atmosphere. This atmospheric freight, detected by regional- and global-scale monitoring networks (see page 2-**18**), commonly travels thousands of kilometres from its source. In 1986, for example, radioactive particles from the Chernobyl disaster circled the Earth within two weeks of the accident (Fig. 2.6).

The transporting capacity of the atmosphere makes it a powerful agent in transferring pollution from one region to another. This process, known as the long-range transport of air pollutants (or LRTAP), depends on the ability of some pollutants to remain in the atmo-

FIGURE 2.6

The spread of radioactive contamination from Chernobyl

The Chernobyl disaster occurred on April 26, 1986. By May 3, radioactive contamination from the damaged reactor had spread over half the northern hemisphere



April 27

April 29

May 1

May 3

Source: Pudykiewicz (1990).

sphere for long periods of time without decaying or being rendered harmless.

Sulphur and nitrogen compounds, chlorinated pesticides, and particles of metals such as mercury and lead, for example, all display this kind of stability in the atmosphere. Although suspended in the air, some of these substances bond to water droplets, dust particles, and other materials. Others undergo chemical reactions that produce new pollutants. Eventually, this material returns to Earth, either with precipitation (a process known as wet deposition) or as dry matter (a process known as dry deposition). Circulation patterns and precipitation determine where the material is eventually deposited. Continuing deposition of contaminants can eventually lead to the buildup of harmful levels of these substances or their by-products in soils, sediments, water, and living tissue.

As a result of long-range atmospheric transport, harmful substances may invade regions that lie hundreds or thousands of kilometres away from their source. Thus, the atmosphere is a principal path for contamination of remote ecosystems in the Arctic (see Chapter 15), and the majority of PCB inputs to lakes Superior, Michigan, and Huron occur via the atmosphere (see Chapter 18). Of all the problems associated with the long-range transport of atmospheric pollutants, the best known and among the most serious is acid rain, or, as it is more properly called, acidic deposition.

Acidic deposition: the extent of Canada's problem[2]

For more than a century, scientists have known that certain industrial processes could produce acidic rain and snow. It was not until the late 1960s, however, that an awareness of its full environmental impact began to develop. The initial concern was the effect of acidic deposition (both precipitation and dry deposition) on freshwater aquatic ecosystems. The eggs and larvae of fish and other aquatic creatures are particularly sensitive to changes in acidity. Thousands of lakes across eastern North America now support little or no life as a result of acidic deposition.

This phenomenon has also been linked to a variety of other problems, including the increasing deterioration of forests in Europe and North America. Sensitive species, like the eastern white pine, show acute injury in a matter of hours, with sulphur dioxide concentrations as low as 25–30 ppb (Federal–Provincial Advisory Committee on Air Quality 1987). In the longer term, it causes foliage to yellow, and, in urban areas, acidic deposition has accelerated the decay of buildings and other structures. The pollutants can also affect human health. Acidic deposition increases the concentration of toxic metals, such as mercury and aluminum, entering both the water and the food chain, and acids in the air impair lung function and increase susceptibility to respiratory diseases.

Vulnerable ecosystems

Acidity is measured on the pH scale, a scale in which a difference of one full unit actually represents a 10-fold change in acidity. A value of 1.0 denotes extreme acidity, whereas a measure of 7.0 is neutral. "Pure" rain, not affected by contaminants of human origin, always contains some natural acids and is therefore slightly acidic, at a pH between 5.0 and 5.6.

In all regions of southern Canada east of Thunder Bay, precipitation now normally has a pH of less than 5.0 (Fig. 2.7), and values lower than 3.0 — about as acidic as weak vinegar — have been recorded (Federal/Provincial Research and Monitoring Coordinating Committee 1990). This contaminated rain exacts a toll on freshwater ecosystems. When the pH of the lakes and rivers falls below 6.0, some particularly sensitive species such as crayfish and mayflies show signs of damage and may even be lost. Below pH 4.5, fish cannot be supported.

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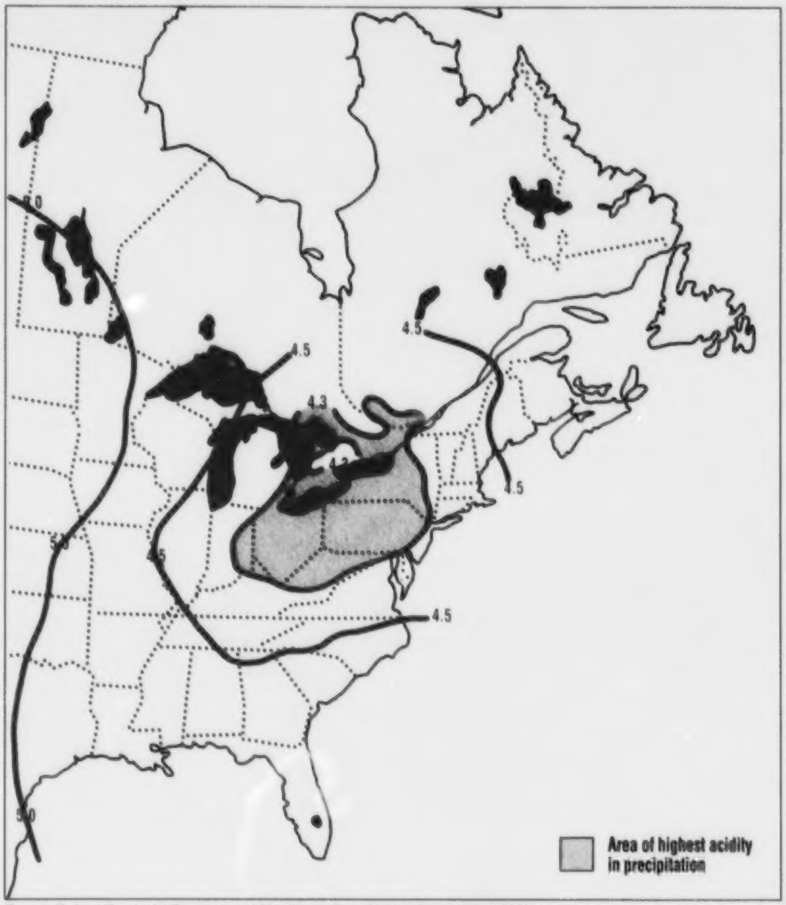
[2] See Chapter 24 for a fuller treatment.

FIGURE 2.7

Mean acidity of precipitation, 1982–87

Some year-to-year variability has occurred, but the general pattern has remained the same. Highest acidity, on average, has been measured in rain and snow falling in southern and eastern Ontario and southwestern Quebec.



Source: Federal/Provincial Research and Monitoring Coordinating Committee (1990).

In Canada, acid rain and dry deposition are primarily the products of sulphur dioxide emissions, most of which come from burning sulphur-containing coal and processing sulphur-containing ore. The sulphur dioxide may remain aloft for many days, during which time it oxidizes to form sulphates that combine with water in the air, forming sulphuric acid. Much of this returns to Earth in precipitation. Even when the sulphate particles do not combine with water, they may fall to Earth and form sulphuric acid in the surface waters. Nitrogen oxides, which react with water in the atmosphere to form nitric acid, are a further source of acidic deposition. These oxides are emitted by all combustion sources, notably automobiles and coal-burning power facilities.

The effects of acidic deposition depend on where it falls. Environments containing natural alkalies, such as limestone, neutralize the acid before it does significant harm to ecosystems. In areas such as southwestern Ontario or the prairies, where limestone is plentiful or alkaline soils predominate, lakes and rivers are more resistant to acidification. Areas in which the rock is predominantly granitic, however, tend to be highly sensitive to acidic deposition (see Fig. 24.8). Approximately 45% of Canada's land area has a low potential to neutralize acidity (Environment Canada 1988).

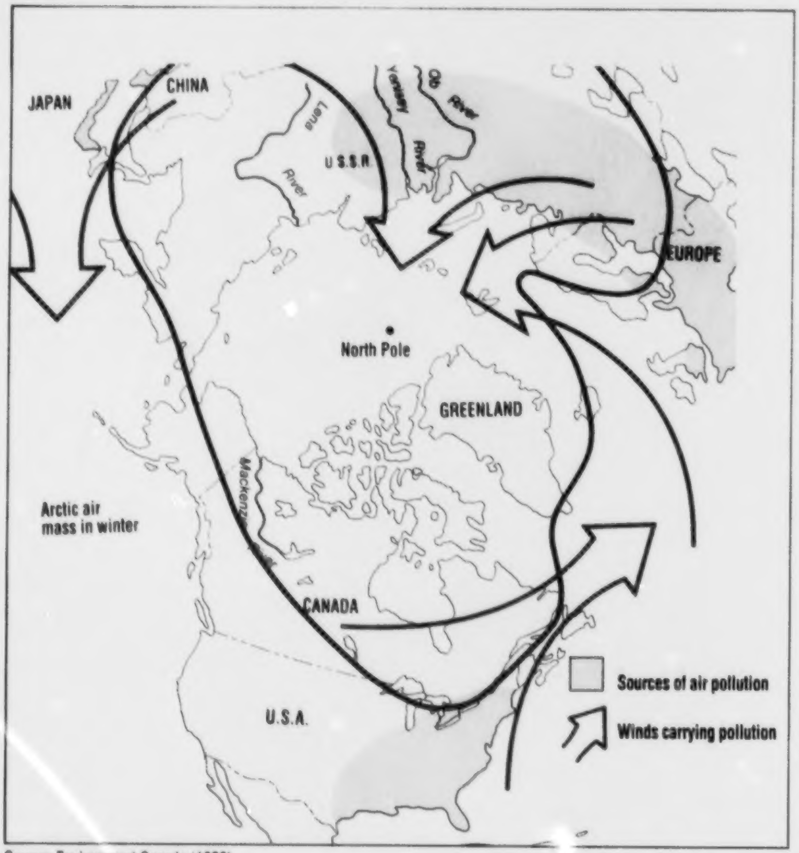
Soils and sediments that are nitrogen-poor are relatively tolerant of nitrates, because these are quickly taken up and used as nutrients by plants. Because most Canadian environments are of this type, nitrates have not yet been considered as serious a factor as sulphates in the acidification of surface water and groundwater in this country. However, continued accumulation of nitrates could eventually increase the nitrogen content of these soils and diminish the effectiveness of this natural buffering process. This may already be under way in Norway, where increasing levels of nitrates have been detected in some lakes (Norwegian State Pollution Control Authority 1987).

Major acidic deposition problems arise where atmospheric circulation patterns connect sources of heavy sulphur dioxide and nitrogen oxide emissions with areas of poor buffering capacity. The largest source of emissions in North America is the continent's industrial heartland around the lower Great Lakes and the Ohio River valley. Smelting operations in the mining country of central Ontario are another major source. In the mid-1980s, eastern Canada alone produced 4.6 million tonnes of sulphur dioxide. Prevailing winds from the west and southwest carry these pollutants across southern and central Ontario, southern Quebec, and the Maritime provinces. Much of the land along this path is vulnerable

FIGURE 2.8

Sources of arctic air pollution

Arctic air pollution is at its peak during the winter, as pollutants build up in the cold pool of air surrounding the North Pole. Winter winds carry pollution primarily from the U.S.S.R. and Europe, with lesser amounts from North America, China, and Japan.



Source: Environment Canada (1989).

to acidification. Similarly, storms moving up the American east coast pick up pollutants from eastern seaboard states and often release them over Atlantic Canada.

Canada's winter weather poses an additional problem. Because much of Canada's winter precipitation occurs as snow, acids can accumulate in the snowpack for months. When the snow melts in the spring, it releases a surge of acidity into nearby rivers and lakes, a phenomenon known as acid shock. The sudden rise in acidity catches some aquatic species at their most vulnerable moment — when they are spawning or when the newly hatched generation is in its early life stages. As a result, many eggs either fail to hatch or produce deformed embryos.

Canadian responses

Since 1970, emissions of sulphur dioxide in both Canada and the United States have largely declined. In the Algoma region of Ontario, some lakes have shown a rapid response to a consequent decline in sulphate deposition. As the pH moved above 5.5, two lakes previously without fish recovered sufficiently that stocks from surrounding areas are populating these lakes (Kelso and Jeffries 1988). Similarly, a study of Clearwater Lake, near Sudbury, Ontario, showed that when sulphur dioxide emissions in the region declined by 50% between 1973 and 1985, the acidity of the water rebounded from a low of 4.1 in 1977 to 4.7 in 1985 (Dillon *et al.* 1986).

The improvements have come about as a result of two decades of Canadian efforts both domestically and internationally. In 1985, Canada, the United States, and the Soviet Union agreed in principle to cut emissions of sulphur dioxide by 30%. Canada immediately followed up with positive action: an internal agreement between the federal government and the governments of the seven easternmost provinces to reduce emissions to 50% of the 1980 levels by 1994. The reductions promised to reduce emissions to a target loading (i.e., rate of deposition per unit area) of 20 kilograms of sulphate per hectare per year (kg/ha per year). The area in which the 20 kg/ha per year target level is exceeded has decreased since 1980, with the most notable improvements occurring in the Atlantic region.

Nevertheless, large parts of eastern Canada remain exposed to destructive levels of sulphate deposition. Even those that have achieved the 20 kg/ha per year target loading may be exposed to further damage. Studies have shown that more sensitive ecosystems can be hurt by sulphate loadings as low as 8–12 kg/ha per year. An encouraging sign, however, was the United States' commitment, in 1990, to cut its sulphur dioxide emissions by 50% in the next decade. Because Canada receives roughly half of its sulphur deposition from the United States, this will cut depositions in Canada by a further 2.2 million tonnes from 1980 levels. Coupled with Canadian efforts, this cleanup should decrease the number of damaged lakes in eastern Canada alone from 13% (100 000 lakes) to 5% (Federal/Provincial Research and Monitoring Coordinating Committee 1990).

Arctic haze

Sparsely settled and far from the cities of the south, the Arctic could be expected to have some of the cleanest air in the world. Yet, ever since the 1950s, pilots and other observers have reported extensive layers of reddish-brown haze in the arctic winter atmosphere. Confined to the lowermost 1 or 2 km of the atmosphere, the haze is composed of fine particles of sulphates, hydrocarbons, soot, and dust, as well as traces of toxic metals and chlorinated pesticides.

Most of the contamination is brought to the Arctic by the prevailing winds, which in winter carry pollutants northward from Europe and Asia (Fig. 2.8). (The winds generally carry polluted air from eastern North America and other major source regions out over the oceans.)

Winter weather conditions allow the incoming pollutants to accumulate. With the onset of prolonged darkness, the high Arctic is no longer warmed by direct sunlight and thus has little heat available to sustain strong vertical currents in the atmosphere. The air tends to form a shallow, stable layer near the surface that keeps pollutants from mixing with air streams at higher levels. This layer also discourages cloud formation and hence precipitation, which would cleanse some of the pollutants from the air. In addition, photochemical processes that might change and decay pollutants come to an end during the long polar night. As a result, average sulphate concentrations in the Arctic rise during the winter to about a third or a half of levels in rural areas of eastern North America (Barrie 1986).

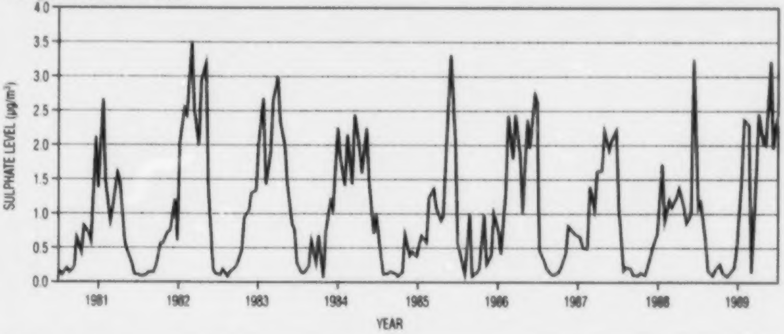
In the summer, arctic pollution levels drop dramatically. Sulphate concentrations are about one-twentieth to one-fortieth of winter levels (Fig. 2.9). The change is in part due to the return of photochemical removal processes, better atmospheric mixing, and more precipitation during the summer, all of which greatly increase the ability of the atmosphere to cleanse itself. Just as important, however, is the change in dominant atmospheric circulation patterns: in summer, the south–north transport is weaker, leading to a lower influx of contaminants.

Although arctic haze is a seasonal phenomenon and the levels of pollution are lower than in the south, the potential for ecological damage is high. Because of the prevalence of sulphates in arctic haze, the possibility of acidification of terrestrial and aquatic ecosystems must be taken seriously. The presence of metals, such as mercury and lead, and chemicals, such as the chlorinated hydrocarbons used as pesticides, raises the possibility of contamination of the food chain. Though concentrations of these substances are comparatively low in the air, they bioaccumulate in the tissues of organisms and biomagnify up the food chains of the region and, at times, reach dangerous concentrations. For example, mercury levels in the muscular tissue of beluga (white whales) taken at five sites across the Canadian Arctic have exceeded the guideline of 0.5 ppm recommended for the safe eating of fish (R. Wagemann, Department of Fisheries and Oceans, personal communication). Findings such as this have raised concerns for the health of those northerners who rely on beluga and other contaminated species for their food supply (see Chapter 15).

FIGURE 2.9

Variations in average weekly levels of airborne sulphates at Alert, N.W.T.

Arctic haze is a seasonal phenomenon, peaking between early January and late April and diminishing to much lower levels during the summer and autumn.



Source: L.A. Barrie, Environment Canada, personal communication.

The haze may also have global ramifications, because changes in the arctic atmosphere may intensify climatic change. The haze absorbs more radiation than a clear arctic atmosphere, and computer models suggest that this leads to a slight warming of arctic air between March and May (Blanchet and List 1987). In addition, the deposition of soot particles on ice and snow may increase the amount of solar energy absorbed by those surfaces and add to this warming effect. These temperature changes could have consequences for weather patterns across the entire northern hemisphere.

GLOBAL IMPACTS

On a global scale, pollutants are causing a reduction in stratospheric ozone, which protects many organisms from ultraviolet radiation. Pollutants are also augmenting the greenhouse effect and increasing the likelihood of a major change in global climate.

Depletion of the ozone layer[3]

Fears that the stratospheric ozone layer might be at risk first erupted in the late 1960s and early 1970s when it was suggested that large numbers of high-flying supersonic aircraft might release enough water vapour and nitrogen oxides into the stratosphere to disrupt the chemical balance of the layer. An international assessment led by the World Meteorological Organization (WMO) found that this was not a serious concern. Instead, it indicated that chlorine compounds might pose a genuine threat to the stratosphere's ozone.

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[3] See Chapter 23 for a fuller treatment.

Direct evidence of serious stratospheric ozone depletion was not forthcoming, however, until May of 1985, when British scientists published their astonishing discovery of a major decline in antarctic springtime ozone at their station at Halley Bay (Farman *et al.* 1985). Further study of data from other stations in the Global Ozone Observing System of WMO (see Box 2.2) and satellite measurements by the U.S. National Aeronautics and Space Administration (NASA) showed the extent of the ozone hole. The "hole" is actually a large area the size of the continental United States in which ozone concentrations are seriously depleted. In 1985, levels were as much as 40% less than they had been a decade before. The hole is a seasonal phenomenon (Fig. 2.10), closely related to the strength of the winter circulation around the south pole. It develops in September and lasts about two months before filling in. Stratospheric ozone depletion has been conclusively linked with emissions from the Earth of chlorofluorocarbons (CFCs), halons, and other substances.

Subsequent research has indicated the existence of a similar disturbed chemistry over the Arctic (Evans 1990). However, ozone depletion over this region is less and the pattern more irregular, because arctic circulation vortices are much less pronounced and less persistent than those in the Antarctic. Declines in stratospheric ozone have also been observed in the mid-latitudes of the northern hemisphere. Environment Canada scientists report that the average total ozone concentration over Toronto for the period 1976–86, for example, was 1.2% lower than it was for the preceding decade (United Nations Environment Programme 1989).

Ozone-destroying substances

Major studies undertaken in the 1970s and 1980s have shown that stratospheric ozone levels are maintained by an extremely complex process involving a very large number of chemical reactions. Pollutants are disturbing the

BOX 2.2

Atmospheric chemistry monitoring in Canada on regional and global scales

Networks have been established across Canada to monitor airborne contaminants of regional and global concern. The data collected contribute to our understanding of the origins, pathways, and fates of such substances.

The Canadian Air and Precipitation Monitoring Network (CAPMoN) began operation in 1983, replacing the Canadian Network for Sampling Precipitation and the Air and Precipitation Network as Canada's national network for monitoring regional-scale air and precipitation quality. As of February 1991, there were over 20 CAPMoN stations, the majority of them in eastern Canada where acidic deposition is most severe (Fig. 2.B2). At all sites, *precipitation* is analyzed for acidity and for the concentrations of several major ions (sulphate, nitrate, chloride, phosphate, ammonium, calcium, magnesium, and potassium). At about half of the sites, *air* samples are taken and analyzed for most of the same major ions, sulphur dioxide, and ground-level ozone. The monitoring of VOCs (important in the formation of ozone) has begun on a trial basis at three stations. The network has plans to begin monitoring nitrogen oxides.

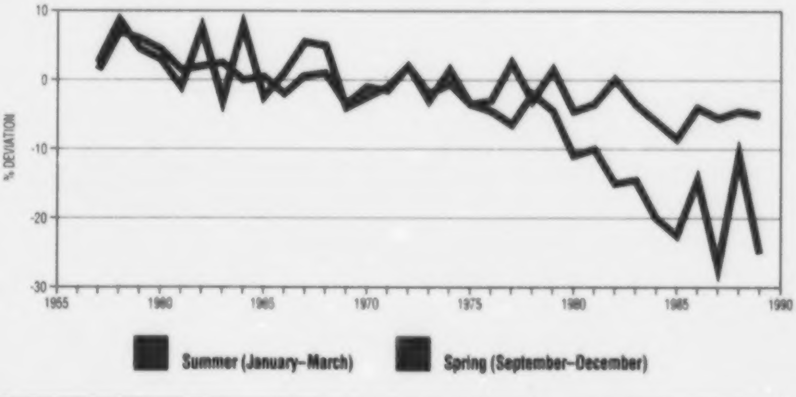
The Global Ozone Observing System (GO$_3$OS) was initiated by the World Meteorological Organization in 1957. Using various techniques, the network collects data on both tropospheric and stratospheric ozone. As of early 1991, the Atmospheric Environment Service (AES) of Environment Canada operated eight Canadian stations in the GO$_3$OS network. In addition, AES serves as coordinator for the network, housing the World Ozone Data Centre, in which ozone data from around the world are organized into a readily accessible computer data base.

Canada also contributes to global monitoring of greenhouse gases. Carbon dioxide levels are measured at four sites: Alert, N.W.T.; Cape St. James, B.C.; Fraserdale, Ontario; and Sable Island, N.S. In addition, at Alert, arctic air pollution is monitored and studied.

FIGURE 2.10

Antarctic total ozone: seasonal deviations from the 1957–77 average of four stations (Argentina Island, Syowa, Halley Bay, and the South Pole)

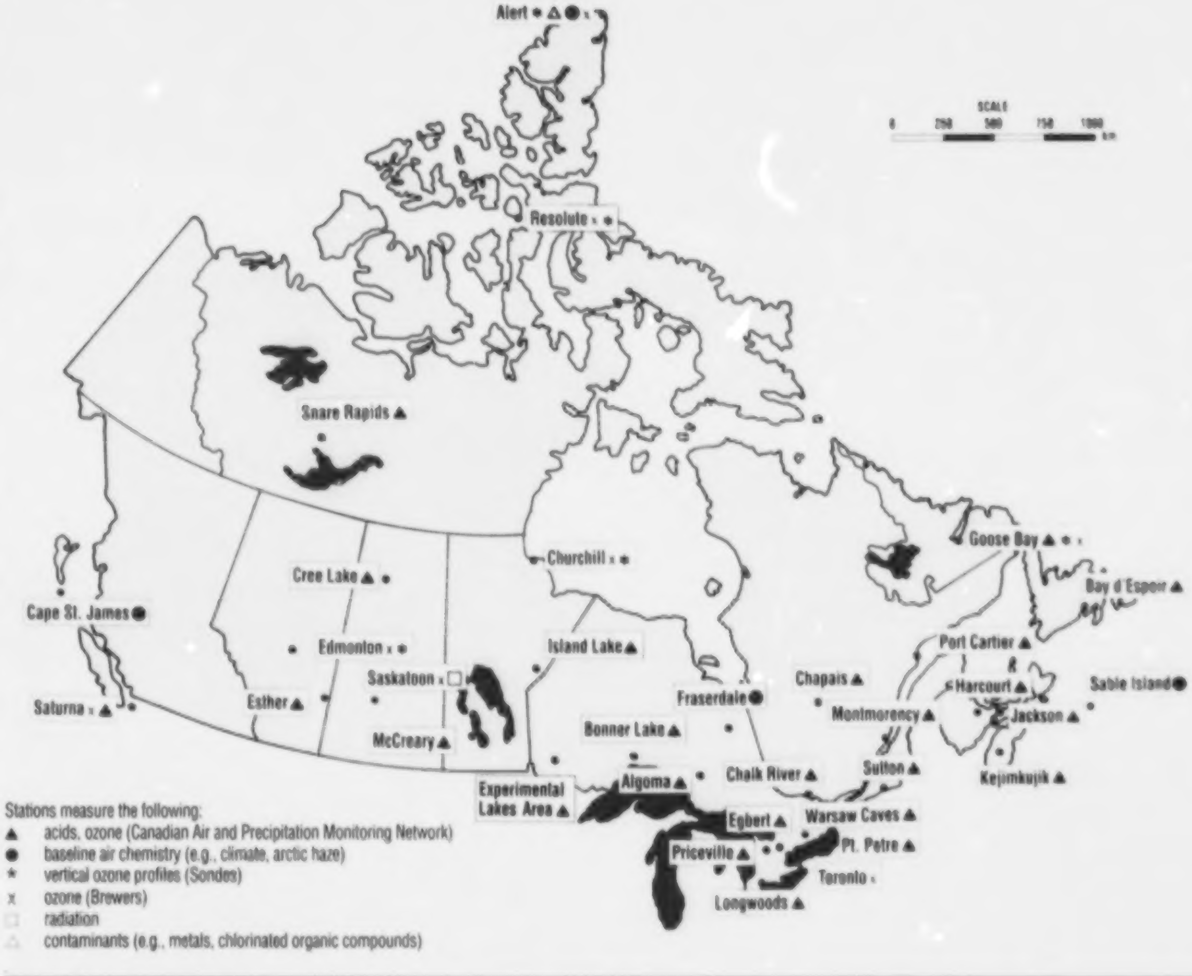
Spring is when the ozone hole is most pronounced. In summer, the hole fills in.



Source: Bruce (1990).

FIGURE 2.12

Environment Canada's network of stations monitoring airborne contaminants of regional and global concern


Alert ★ △ ● x
SCALE
0 250 500 750 1000 km
Resolute x ★
Snare Rapids ▲
Goose Bay ▲ ★ x
Bay d'Espoir ▲
Churchill x ★
Cree Lake ▲ ★
Cape St. James ●
Edmonton x ★
Island Lake ▲
Saskatoon x □
Port Cartier ▲
Chapais ▲
Harcourt ▲
Sable Island ●
Fraserdale ●
Saturna x ▲
Esther ▲
Montmorency ▲
Jackson ▲
Bonner Lake ▲
McCreary ▲
Sutton ▲
Kejimkujik ▲
Chalk River ▲
Algoma ▲
Experimental Lakes Area ▲
Egbert ▲
Warsaw Caves ▲
Priceville ▲
Pt. Petre ▲
Toronto x
Longwoods ▲
Stations measure the following:
▲ acids, ozone (Canadian Air and Precipitation Monitoring Network)
● baseline air chemistry (e.g., climate, arctic haze)
★ vertical ozone profiles (Sondes)
x ozone (Brewers)
□ radiation
△ contaminants (e.g., metals, chlorinated organic compounds)

Source: L.A. Barrie, Environment Canada, personal communication.

equilibrium of the process. Studies have linked the depletion of the layer primarily to increasing atmospheric quantities of CFCs — chlorine-containing human-made gases that were touted as the perfect industrial chemicals when CFC-12 was first made in 1928 (Rowland 1988). CFCs are long-lasting and nontoxic, do not accumulate at ground level, and are excellent heat absorbers. They are widely used as refrigerants, foaming agents, and solvents. They were banned for use as propellant gases for antiperspirants and hair sprays in Canada in 1980, but are still used in this manner in other areas of the world.

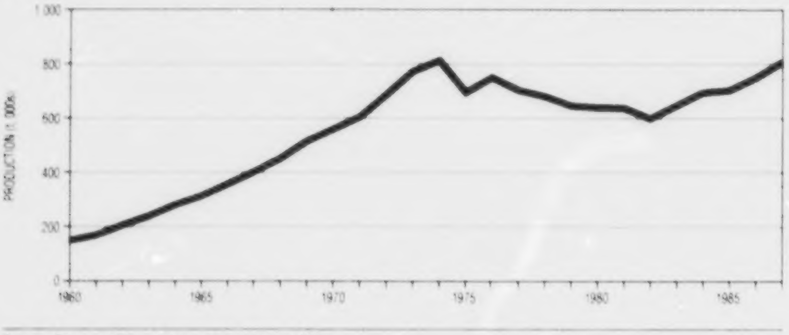
Halons are another family of chemicals that threaten the ozone layer. Used extensively in fire extinguishers, halons contain carbon, fluorine, bromine, and sometimes chlorine. Since bromine is a powerful catalyst for ozone destruction, the halons have — molecule for molecule — a three to six times greater ozone-destroying potential than CFCs. Other compounds, such as methyl chloroform, are also harmful to ozone and increasing in atmospheric concentrations, but CFCs are still responsible for the lion's share of the damage.

Because they are very stable, it is estimated that CFCs can survive in the atmosphere for more than 75 years, with some forms (CFC-12) persisting longer than 100 years (United Nations Environment Programme 1989). Their disintegration is guaranteed when

FIGURE 2.11

Global production of the most common CFCs, CFC-11 and CFC-12, 1960–87

The world production of CFCs increased in the mid-1980s, after a decline in the middle and late 1970s, when their use in spray cans was restricted. The developed world makes and consumes 80% of all CFCs. Canada's contribution is 3%.



Source: Chemical Manufacturers Association (1988)

they are transferred to high altitudes and exposed to harsh ultraviolet radiation, but the destruction takes place exactly where the CFCs will do the most harm — in the ozone layer.

One of the products of CFC breakdown is chlorine. Through a cyclical process of reactions, a single chlorine atom can ultimately destroy 100 000 molecules of ozone. (For a sketch of the process, see Figure 23.6.)

Since 1974, the world's nations have produced nearly 1 million tonnes of CFCs a year (Fig. 2.11). Canada is responsible for some 3%. Annual world production of halons exceeds 21 000 t. Not all of this is released immediately into the atmosphere. A significant stock of these compounds remains stored inside products such as CFC-containing air conditioning units. For example, relatively little halon is released each year, but 15 times the annual emissions are stored in extinguishing systems. Consequently, even if production were halted completely now, substantial emissions of these gases would continue for some time in the future.

Impacts of diminishing ozone

The continuing depletion of ozone in the stratosphere is expected to have a number of significant impacts. It is estimated that a 1% decrease in stratospheric ozone could cause a 1.5% increase in the amount of biologically damaging ultraviolet radiation reaching the Earth's surface (Urbach 1989). Consequences for human health are expected to include an increased incidence of skin cancer, immune system disorders, and increased eye diseases, notably cataracts.

Aquatic life in the surface waters of lakes and oceans is vulnerable as well. Indeed, all major ecosystems could be altered, because they are dependent on photosynthesis by green plants, which is impaired by excessive ultraviolet radiation. Experiments with yields of common crops such as wheat, rice, corn, and soybeans show a distinct decrease in yields by about 1% for every 1% decline in total ozone (Grant 1989).

In addition, as a greenhouse gas, ozone plays a key role in determining the thermal characteristics of the stratosphere. A decrease in ozone concentrations will lead to changes in the temperature structure of the stratosphere, which in turn will have some impact, not yet well understood, on general atmospheric circulation and climate.

Canadian responses

The most effective international response to atmospheric change so far has focused on the problem of CFCs. The first steps were taken in 1977 when the United Nations Environment Programme drew up a World Plan of Action on the Ozone Layer. At about the same time, Canada, the United States, and various European countries began to restrict the use of some CFCs as aerosol propellants. The discovery of the antarctic ozone hole in 1985, however, brought a new sense of urgency to the situation and a recognition that much more drastic international action was required. This led, in 1987, to the signing of the Montreal Protocol on Substances that Deplete the Ozone Layer, in which 24 nations committed themselves to a 50% reduction in the use of CFCs and other ozone-destroying substances, such as halons, by the end of this century. The protocol is now ratified by more than 50 nations.

Many scientists believe, however, that even stronger action must be taken. At a London meeting of the parties to the Montreal Protocol in June 1990, Canada announced its intention to eliminate CFC production entirely by 1997, three years earlier than the more generally accepted target date. Industrialized nations also agreed to phase out production of CFCs and halons by 2000.

Reducing and eliminating the ozone-destroying substances, by promoting conservation and by developing alternatives that are not in themselves dangerous, will entail enormous expense. However, the money spent will benefit not only the ozone layer. It will also help to combat climatic warming: CFCs alone are now responsible for almost one-quarter of the enhanced greenhouse effect attributable to human activity (Intergovernmental Panel on Climate Change 1990*a*).

Global warming[4]

The greenhouse effect is largely sustained by the presence of carbon dioxide and water vapour in the atmosphere. Other important natural gases are methane, nitrous oxide, and tropospheric ozone. Human activities are augmenting the natural greenhouse effect, largely through emissions of these gases, emissions of synthetic greenhouse gases (e.g., CFCs), and changes in land use and cover.

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[4] See Chapter 22 for a fuller treatment.

Climbing levels of carbon dioxide

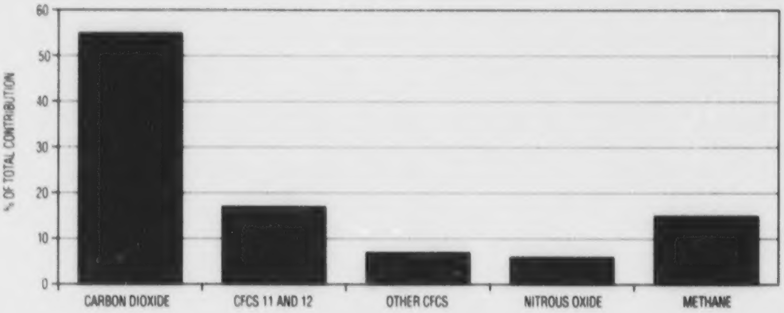
During the 1980s, carbon dioxide emissions alone were responsible for over 50% of the increased potential for warming of our atmosphere (Fig. 2.12). Today, atmospheric carbon dioxide is more plentiful than at any time in the past 160 000 years. Analyses of ice cores from polar ice caps have shown that, although atmospheric carbon levels varied considerably over that period, they remained between 190 and 290 ppm by volume (ppmv). Low concentrations of carbon dioxide occurred during cold glacial periods and high concentrations during the warm interglacials (Barnola *et al.* 1987).

The Earth is currently in a warm interglacial period. Since the beginning of the industrial revolution, carbon dioxide concentrations have continued to rise. Today, the amount in the atmosphere stands at about 355 ppmv, 20% more than the highest values over the previous 160 000 years. This increase is very sudden, in comparison with the time scale of previous geological changes. Yet the levels continue to mount, as the burning of fossil fuels adds about 5 billion tonnes of carbon a year to the atmosphere — an annual quantity 10 times larger than at the turn of the century (Marland 1989). At the same time, the forests that absorb great quantities of carbon dioxide continue to fall. This adds as much as 2 billion tonnes to the global total of atmospheric carbon every year.

FIGURE 2.12

The relative contribution of greenhouse gases to global warming during the past decade

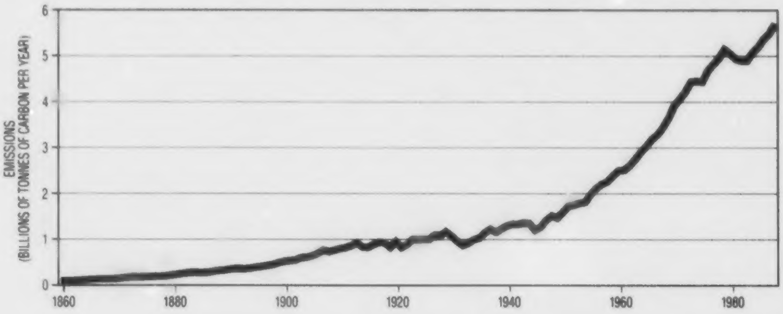
The primary significance of carbon dioxide is apparent, but other gases, notably CFCs and methane, have grown in importance.



Source: Intergovernmental Panel on Climate Change (1990*a*).

FIGURE 2.13

Global carbon dioxide emissions from the burning of fossil fuels, 1860–1988



Sources: Keeling (1973); Marland *et al.* (1989).

On a per capita basis, Canadians are among the highest carbon dioxide producers in the world — emitting about 4.4 t of carbon per person per year. Most of this comes from the burning of fossil fuels (Fig. 2.13), and the amount continues to increase by 1% each year. Unless substantial controls are applied, carbon dioxide levels in the atmosphere could, within a century, rise to double those that prevailed at the beginning of the industrial revolution. If the correlation between carbon dioxide levels and global temperatures continues to hold, then it is logical to expect that the Earth will become warmer than at any time in the past several hundred thousand years.

Other greenhouse gases

In addition to carbon dioxide, other greenhouse gases are increasing in concentration. Methane, commonly known as swamp gas because it is prolifically produced in swamps and other wetlands, varied from 0.6 to 0.9 ppmv in preindustrial times. Levels are now up to 1.7 ppmv and increasing by almost 1% each year. About 50% of the methane has biological origins: decay in wetlands and the increasing area covered by rice paddies, and fermentation associated with digestive processes of the world's ruminant animals. The expanding food needs of a rapidly growing population will continue to increase methane levels for the foreseeable future, unless dramatic changes in food preference occur.

Emissions of oxides of nitrogen are also rising. Like methane and carbon dioxide, these gases occur naturally, but levels are climbing due to human activities — especially the burning of fossil fuels and the widespread use of ammonia fertilizers. A smaller but significantly increasing source of global warming is tropospheric ozone. Levels are climbing with the growing emissions of nitrogen oxides and VOCs. Finally, there are the CFCs — synthetic gases with an extremely high warming potential. Although now being phased out, their effect may last for decades because of their long life span in the atmosphere.

Although a doubling of carbon dioxide alone will probably not occur for some time, an equivalent to doubling by the combined effect of all greenhouse gases could occur as early as 2025, unless remedial measures are taken (Intergovernmental Panel on Climate Change 1990*a*).

Predicting the results

The results of these changes for our global climate are difficult to predict. The computer models that are used to simulate climate and to project the response of the atmosphere to increasing concentrations of greenhouse gases cannot replicate the full complexity of the atmosphere and all of the processes affecting it. However, the major modelling teams in the world, using somewhat different assumptions and mathematical formulations to simulate the processes of the climate system, have arrived at similar conclusions. These suggest that with a "doubled carbon dioxide atmosphere," average world temperatures will rise somewhere between 1.5°C and 4.5°C, although the full warming effect will not be felt until several decades later due to ocean uptake of heat. If this increase seems small, it should be remembered that over the past millennium, world temperature averages have varied by no more than 1°C and that the estimated difference between our present average and that of the last ice age is only about 5–7°C. Above all, the predicted rate of change is unprecedented since at least the last glaciation. One of the most advanced atmospheric general circulation models now available was developed by Environment Canada scientists. They recently completed an experiment that predicts that for an equivalent to doubling of carbon dioxide, the Earth will warm by an average 3.5°C. The shift to warmer temperatures will bring with it a number of other climatic alterations. Increased global evaporation and precipitation will occur, but with major regional differences in the frequency, amount, and seasonal distribution of precipitation. All of the models conclude that polar regions will experience much greater warming than the global average in winter. The polar ice caps will be affected by a combination of increased snowfall and a longer, warmer melt season at their margins. Warming should lead to the melting of sea ice and permafrost decay. Sea levels, already undergoing a mean global rise of about 10–20 cm per century, could rise an additional 65 cm by 2100, largely because of thermal expansion and the increased melting of glacial ice (Intergovernmental Panel on Climate Change 1990*a*). Wind patterns and oceanic currents would change, but in ways not yet well understood.

Exactly how these changes will manifest themselves in a country as climatically diverse as Canada is difficult to predict. Scenarios are discussed in the chapter on climatic change in this report (see Chapter 22). However, Canada has the longest coastline of any country in the world, has permafrost under half its land area, and is highly dependent on climatically sensitive activities such as agriculture, forestry, and fisheries. Without the adoption of major response strategies by our society, it is almost certain that the losses will outweigh any gains, such as extended navigation seasons on the Great Lakes and longer growing seasons.

Even with aggressive and immediate global efforts to reduce emissions of greenhouse gases, we are unlikely to avoid the equivalent of carbon dioxide doubling. Theoretically, greenhouse gas increases should already have caused global temperatures to rise by somewhere between 0.5°C and 1°C. Indeed, there is evidence to suggest that a warming of this magnitude has already taken place (see Fig. 22.5). Six of the seven warmest years recorded since 1861 have all occurred since 1980. However, the 1980s have also witnessed episodes of exceptionally cold weather, and the warm years and droughts of the 1980s are still within the bounds of normal climatic fluctuation. As yet, it is still too early to declare that significant change is occurring, and at least another decade of increased temperatures will be necessary to confirm that the warming process is indeed under way.

Meeting the challenge

Even without a clear signal that significant warming is in progress, it is imperative that decisive action to address rising greenhouse gas levels be taken now. The concluding statement of the "World Conference on the Changing Atmosphere: Implications for Global Security," held in Toronto in 1988, recommended a 20% reduction below 1988 levels in carbon dioxide emissions by 2005. Half of these reductions would be achieved by improvements in energy efficiency and the other half by the use of alternatives to fossil fuels.

The federal government has set as its target the stabilization of greenhouse gas emissions at 1990 levels by the year 2000. The City of Toronto has resolved to reduce net emissions to meet the goals set at the conference by 2005. Yet even with these targets applied worldwide, the level of atmospheric carbon dioxide will continue to climb. According to the Intergovernmental Panel on Climate Change, stabilization of carbon dioxide concentrations will necessitate a global reduction of human-related carbon dioxide emissions of *over 60%!*

RESPONDING TO ATMOSPHERIC CHANGE

Atmospheric pollution is the price the world is now paying for industrialization, and yet we cannot simply put an end to it by dismantling the apparatus of industry. To do so not only would destroy the economic foundations of the developed countries but also would frustrate the aspirations of the rest of the world for greater material security and prosperity. Our best hope for solving this dilemma lies in the concept of sustainable development (see Chapter 27) put forward in the Brundtland Report (World Commission on Environment and Development 1987).

A major Canadian strategy is to work toward greater energy efficiency and conservation. This can save substantial sums of money, while reducing greenhouse gases, acid rain, and toxic emissions. But this will not be easy. Firstly, industrial adjustments have to be made, and, because these can be costly, it is difficult to build agreements for taking action. Secondly, although our knowledge of atmospheric pollution has advanced considerably in recent years, our understanding of many processes is still incomplete. The resulting uncertainty makes it more difficult to build the sense of public commitment needed to support decisive responses. Finally, there are challenging political problems to be resolved where pollutants cross international boundaries or affect the atmosphere globally.

These difficulties are counterbalanced to some degree because many of our atmospheric pollution problems are linked to each other. Reductions in sulphur dioxide emissions, for example, not only have greatly improved local air quality but also have reduced the acidification of lakes and soils. Similarly, the banning of CFCs not only would prevent further increases in the rate of destruction of the ozone layer but also would help to slow down the process of global warming.

At the local level, major improvements in air quality have been achieved in the past 20 years. However, some serious problems remain, such as ground-level ozone and airborne toxic substances. Through tighter motor vehicle emission controls introduced in 1987 and 1988, emissions of nitrogen oxides and VOCs will be held within 1985 levels until the turn of the century. However, current forecasts predict that, unless further measures are taken, Canadian emissions of nitrogen oxides and VOCs will begin a gradual and sustained increase thereafter.

In November 1990, the Canadian Council of Ministers of the Environment endorsed an action plan that could reduce national emissions of nitrogen oxides by 11% and VOCs by 16% from 1985 levels by the year 2005. The first phase of the management plan for nitrogen oxides and VOCs, to be implemented by 1995, will establish both a national preventive program, by setting stringent standards for new emission sources, and local remediation programs in ground-level ozone problem areas, through measures such as retrofitting existing emission sources with less polluting equipment (Canadian Council of Ministers of the Environment 1990).

In addition, a joint Transport Canada/Environment Canada plan has been developed to look at opportunities to reduce emissions associated with internal combustion engines and the fuels that power those engines — emissions that include carbon dioxide, carbon monoxide, nitrogen oxides, diesel particulates, and a variety of unburned or incompletely burned hydrocarbons (Transport Canada and Environment Canada 1989). The plan will impose the most stringent regulations possible with present technology to control emissions from on-road internal combustion engines. The composition of fuels will be altered and changes in fuel-handling procedures introduced to reduce VOC releases through evaporation. The plan will also reduce emissions from numerous other sources, including aircraft, boats, and ships as well as industrial engines using gasoline and diesel fuels.

At the same time, action is being taken to identify and improve our understanding of a much broader range of atmospheric pollutants. Hundreds of potentially toxic substances in our air are unregulated and uncontrolled because we do not know enough about their effects on the environment and their interactions in the atmosphere. The *Canadian Environmental Protection Act* of 1988 took a major step toward assessing their impact when it authorized the establishment of a Priority Substances List identifying a range of chemical compounds to be examined over a five-year period. Further priorities are being identified by the Federal–Provincial Advisory Committee on Air Quality. In the future, we can expect not only an improvement in local air quality but also a lessening of problems, such as acidic deposition, which are associated with the long-range transport of atmospheric pollutants.

The prognosis for an early resolution of the problems of global atmospheric change — the depletion of the ozone layer and the enhancement of the greenhouse effect — is much less optimistic, however, because decisive action on these issues will require an unprecedented degree of international cooperation. Although major progress has been made toward protection of the ozone layer, international agreements on global warming will be far more complex, because the warming is caused by activities central to modern society. Although the industrialized countries of the world bear much of the responsibility for the creation of these problems and must shoulder most of the burden of resolving them, adjustment may be even more difficult for the less developed countries.

Because forests absorb carbon dioxide, deforestation in tropical Africa, Asia, and Latin America is currently adding somewhere between 1 and 2 billion tonnes of carbon to the atmosphere every year. With the pressure of rapid population expansion and the limitation of economic choice imposed by underdevelopment, forest clearing has been necessary to meet immediate and growing needs for fuel, timber, and agricultural land. As long as population growth continues, deforestation can be slowed down only by reducing poverty and by combining greater agricultural efficiency with new opportunities beyond agriculture for the local people. The developing countries also look to industrialized nations such as Canada to move from net deforestation to aggressive reforestation.

Developing countries see industrialization as one route out of their dilemma, and many fear that additional environmental responsibilities will slow the pace of material progress and add greatly — perhaps prohibitively — to its costs. Nevertheless, under "business as usual" scenarios, the Third World will account for 45% of the world's fossil fuel emissions by 2025, compared to 25% today (Intergovernmental Panel on Climate Change 1990*a*). Ways must be found for industrialized countries to assist others in their struggle toward economic development, through the provision of low-emission technologies and better means for energy conservation. Even industrialized nations like Canada, however, are finding it difficult to curb production of carbon dioxide sufficiently to meet the emission target cutbacks set for the turn of the century. The world needs, as the Brundtland Commission pointed out, "an efficiency revolution." Our atmosphere, and indeed the Ecosphere itself, depends on it.

In many respects the nations of the world have made a good beginning in dealing with the problems of atmospheric pollution. But beginnings are not solutions, and the most difficult and challenging issues now lie ahead of us. Guided by knowledge that is imperfect, we have to weigh the certainties of sometimes costly economic adaptation against the possibilities of unprecedented ecological change. If we decide that we must make a wholehearted attempt to minimize our impact on the atmosphere, the costs will be considerable. If we decide to do nothing, however, and wait to see what the future will bring, the costs could be far greater.

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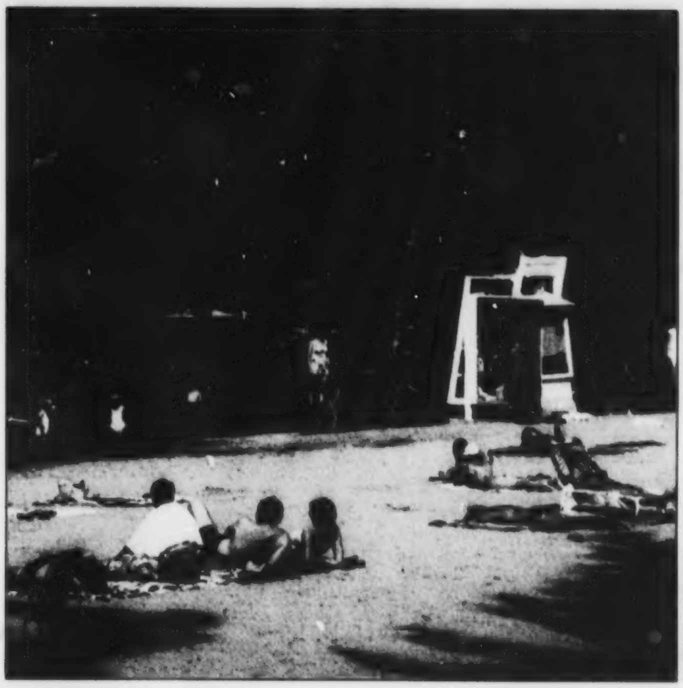

COURTESY OF NATIONAL CAPITAL COMMISSION

HIGHLIGHTS

Canadians are the world's second largest per capita users of water. The average daily household use is 360 L per person. Municipalities, agriculture, transportation, energy, recreation, and industries, including oil, pulp and paper, and mining, are major water-using sectors in Canada.

▪

One in four Canadians relies on groundwater for his or her domestic water supply, and the remainder rely on surface water. Both sources of water are coming under increasing threats to both quality and supply.

▪

Contamination of surface water and groundwater is resulting from industrial plant effluents, runoff from agriculture, urban and industrial areas, and forestry, landfill leachates, poorly treated sewage, and long-range transport of airborne contaminants.

▪

Dioxins and furans have been found in sediments and biota of waters downstream from pulp and paper mills using chlorine bleaching. There is justification for the concern that if these persistent fat-soluble contaminants reach high enough levels in the aquatic food chain, humans could be affected through their food.

▪

Although no national drinking water monitoring program exists, regional studies to date indicate that the quality of most Canadian drinking water meets Canadian drinking water guidelines.

▪

In 1989, 70% of Canadians residing in communities of over 1 000 had some form of municipal sewage treatment, up from 63% in 1983. Pollution from combined and storm sewers and inadequately treated sewage sometimes result in beach closures around many cities because health standards are not met.

▪

Action to remedy past mistakes is in progress for the Great Lakes and St. Lawrence River and is planned for several areas of concern, including Atlantic harbours and coasts, as well as the Fraser River basin. Already, biomonitoring has indicated a decline in a number of toxic contaminants in the Great Lakes. To prevent further degradation and to improve highly impaired waters, a national regulatory action plan including control of effluents containing dioxins and furans and new limits on other effluents from the pulp and paper industry is to be in full force by 1994.

▪

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> “In an age when man has forgotten his origins and is blind even to his most essential needs for survival, water along with other resources has become the victim of his indifference.”
>
> — Rachel Carson (1962)

INTRODUCTION

Abundance, power, and beauty of fresh water have always been an important part of Canadian life and identity. Fresh water is Canada's lifeblood: vital for ecosystems, important to the quality of life of Canadians, and a key element for economic and recreational activities. Perhaps because water is so readily available, many Canadians fail to realize just how much stress human demands for water are placing on natural systems.

The stress takes many forms. The growth of large urban centres, increased industrial activity, and an agricultural sector dependent on chemicals are overloading the natural ability of water bodies to break down wastes and altering natural flow patterns. Acid and toxic rain are killing some forms of freshwater life or interfering with their ability to reproduce. Hundreds of chemical substances in use in Canada and around the world are contaminating Canadian lakes, rivers, and groundwater, and some are entering food chains.

The quality of water has been impaired in many parts of Canada. The Fraser River, British Columbia, is contaminated with poorly treated sewage, landfill leachates, wood treatment chemicals, runoff from forestry and agricultural operations, and pollutants from pulp and paper mills and other industrial plants. Water quality in the Red River, Manitoba, like other prairie rivers, is degraded due to agricultural runoff and inadequately treated sewage. The Great Lakes and the St. Lawrence suffer from industrial and municipal pollution, as well as urban and agricultural runoff and atmospheric deposition. And Prince Edward Island's groundwater is threatened with contamination by agricultural pesticides.

To meet their social and economic goals, people have, to some extent, altered distribution of fresh water, but they still depend on the global water cycle (Fig. 3.1) to refill natural and artificial water bodies. Because of high demand, some areas of Canada, particularly the southern prairies, are facing growing water shortages. In the future, climatic change caused by people may exacerbate current water supply problems by altering the water cycle, which, in turn, may affect water distribution (see Chapter 22).

As much as human beings have used technology to distance themselves from the environment, they are still part of a finite Ecosphere (see Chapter 1). Fresh water must be shared among all species. Ecological interdependence means that the threat that human-caused problems of contamination and altered distribution patterns of fresh water pose to the securities of other entities is also ultimately a threat to human survival.

Economic and social uses of fresh water often compete with the needs of other species and harm ecosystems, including people. For example, capturing huge volumes of water behind hydroelectric dams has led to elevated levels of mercury in aquatic and terrestrial organisms, in and near the flooded area. Many human activities that do not directly involve water use have affected freshwater ecosystems: 80% of the Fraser River delta wetlands, up to 71% of prairie wetlands, 68% of southern Ontario wetlands, and 65% of Atlantic coastal marshes have been lost — mostly drained for agriculture; and 14 000 lakes in eastern Canada no longer support life, because of acid-forming substances generated by people in Canada and other countries who operate smelters and refineries, or who burn fossil fuels for manufacturing, space heating, or transportation (see Box 3.1; also Chapter 24).

Preserving freshwater ecosystems and the quality and availability of Canada's fresh water is perhaps the most pressing of the many environmental challenges on the national horizon. Over the last several decades all levels of government have collected data on water quantity and quality and the aquatic life it supports. Unfortunately, most of the data have been collected for specific programs and projects of limited environmental and geographical scope.

This fragmented approach is the product of both cost considerations (data collection and analysis are expensive) and the issue-driven approach that has characterized water management for the past two decades. As a result, a national profile of the state of Canadian fresh water — particularly with respect to water quality — is, in essence, a "patchwork" of data drawn from specific programs and regional ecosystem studies. For a fuller appreciation of the state of Canada's water and aquatic ecosystems, this chapter should be read in conjunction with Chapters 15–19 on the Arctic, the lower Fraser River basin, the prairie grasslands, the Great Lakes, and the St. Lawrence River, and Chapter 24 on acidic deposition.

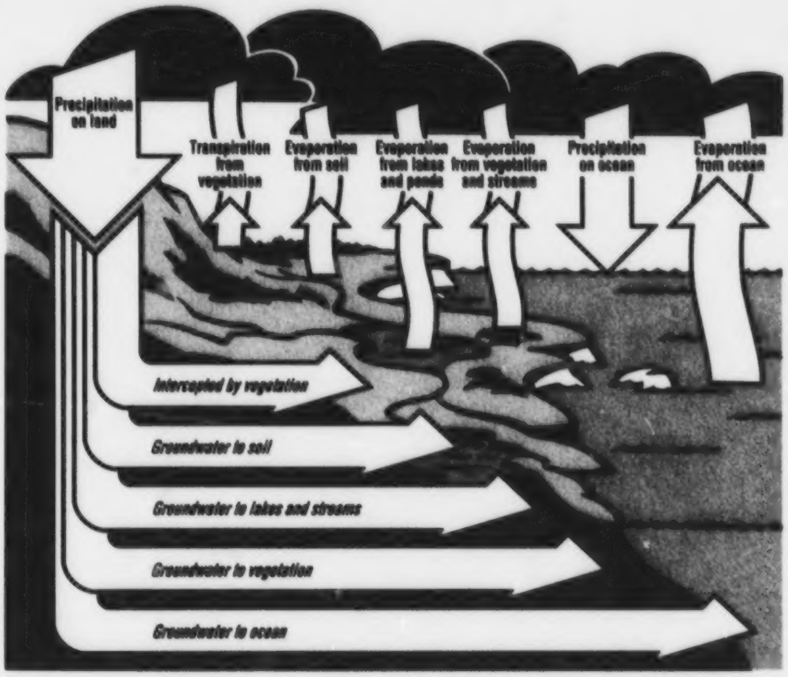
Given this context, the first part of this chapter presents a general overview of Canada's water — its distribution and quality and the stresses imposed upon aquatic ecosystems by select human activities, for example, agricultural practices and discharges from urban and industrial sources. Following this general treatment is a more in-depth discussion of specific contaminants (e.g., dioxins and furans) of concern to the public because of their potential detrimental effects upon the aquatic ecosystem. Drinking water is of particular concern to the public because of its human health implications, and this issue is addressed in the last section. The conclusion comments on some select key trends and offers suggestions for overcoming some of the current data deficiencies.

CANADA'S ENDOWMENT OF FRESH WATER

Oceans contain most of the water on the planet. Only a small proportion, some 2.7%, of Earth's water is fresh, and only a tiny percentage, little more than 0.01%, is both fresh and accessible, in lakes, rivers, soil, and the atmosphere. Almost all of the 2.7% is locked up in glaciers and polar ice or buried deep underground (Pearse *et al.* 1985).

FIGURE 3.1

The water cycle


Precipitation on land
Transpiration from vegetation
Evaporation from soil
Evaporation from lakes and ponds
Evaporation from vegetation and streams
Precipitation on ocean
Evaporation from ocean
Intercepted by vegetation
Groundwater to soil
Groundwater to lakes and streams
Groundwater to vegetation
Groundwater to ocean

Source: Pearse *et al.* (1985).

In Canada, given its northern environment, snow and ice are significant repositories of fresh water. Canada's 100 000 glaciers alone contain 1.5 times the volume of its surface water. Groundwater, somewhat more accessible than water in glaciers but not as readily replenished as surface water, represents about 37 times the total amount of water contained in rivers and lakes (Science Council of Canada 1988). Groundwater flows extremely slowly through underground channels, or aquifers, of sand, gravel, or porous and fractured rock. Where it emerges at the surface, groundwater augments the flow in streams and rivers.

Canada may have more lake area than any other country. Our lakes and rivers cover nearly 8% of the country and contain enough water to flood the entire nation to a depth of more than 2 m (Science Council of Canada 1988). Lakes are both massive storage tanks and regulators of flow. During periods of high precipitation and snowmelt, they store water. The water is released gradually, feeding rivers through periods of low precipitation. Wetlands, which act like sponges, perform the same functions as lakes, providing extra protection against flooding. Also, if water is considered the "lifeblood" of the environment, then wetlands are its "kidneys," filtering the waters of lakes, rivers, and streams and reducing pollution. Wetlands (both fresh and salt) cover nearly 14% of Canada's land surface.

Water flow in rivers (annual runoff) is the best measure of the fresh water that is continuously renewed through the hydrologic cycle. However, only a small portion, approximately 1%, of water stored in lakes and aquifers is renewed annually. Canadian rivers discharge 9% of the world's renewable water supply to the Pacific, Arctic, and Atlantic oceans, with the St. Lawrence River and Mackenzie River being the largest contributors. Therefore, Canada's share of the world's renewable water supply is not disproportionate to its 7% share of the global land mass.

Though Canada enjoys a generous overall endowment of renewable fresh water (measured as flow in rivers), the distribution of rivers does not coincide with concentrations of population and economic activity: 60% of Canada's fresh water drains north to the Arctic Ocean and Hudson Bay, whereas 90% of Canadians live within 300 km of the Canada–U.S. border. People alter distribution of fresh water for immediate human convenience. They increase soil moisture in dry areas by irrigation, they build diversions and dams and reservoirs for water supplies and hydroelectric power, and they drain wetlands and convert them into farm fields and subdivisions (Fig. 3.2). Altering the distribution of the fresh renewable water supply cannot be done without far-reaching effects on ecosystems, however. For example, fresh water that drains into the sea is not wasted; it regulates climate and currents and sustains fish populations. Nor are wetlands expendable. They provide habitat for a wide range of plants, fish, birds, and other wildlife, including about one-third of Canada's endangered and vulnerable species as designated by the Committee on the Status of Endangered Wildlife in Canada (see Chapter 26 on the significance of loss of wetlands).

People are also changing the distribution and availability of water in a more indirect fashion. The scientific community now agrees that human-induced global warming will become significant around the middle of the next century. Even relatively small increases in the average global temperature could cause large problems of water supply in arid and semiarid regions. A summary of Canadian research (Canadian Council of Ministers of the Environment 1990) concluded that most scenarios would lead to a decrease of 25–50% in net supply in the Great Lakes and St. Lawrence basins, and to higher streamflow and floods during spring thaw in watersheds at high latitudes. Rising sea level threatens to allow salt water to penetrate groundwater supplies in coastal areas. Canada's Pacific coast will likely experience increased winter precipitation and an increase in landslides and local floods. The drying up of major marsh areas in Canada's central region would reduce wildlife habitat. The prairies are likely to face an increase in the frequency and severity of drought (see Chapter 22).

BOX 3.1

Atlantic Canada's small waters at big risk

When it comes to rivers, lakes, and ponds, small is often beautiful. Generally, small water bodies are more ecologically valuable than larger ones. They provide ideal waterfowl breeding and fish spawning habitat and are usually not affected by human recreational activities, being too small for boating and cottages and too remote for easy access. In Atlantic Canada, however, small also means threatened.

On average, the Atlantic provinces receive between 10 and 15 kg of anthropogenic sulphate per hectare every year — 70% from sources outside the region. This is often more acidity than the ecosystem can actually absorb without major damage. Smaller water bodies are particularly susceptible to acidification because of their relatively small volume, shallowness, and geological setting.

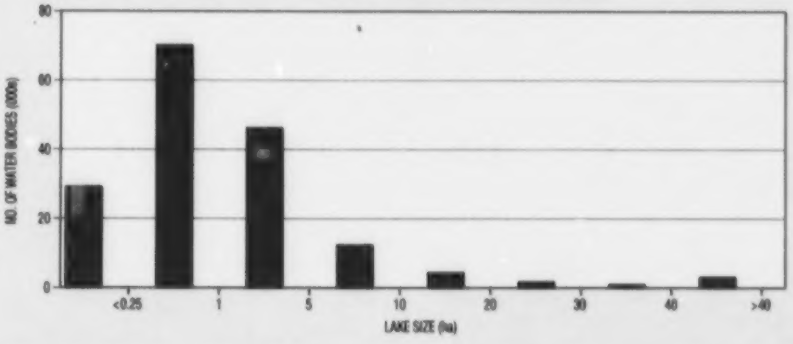
The degree of the potential problem was recognized recently when a satellite survey of the Atlantic region picked up nearly 100 000 water bodies that had not been part of standard inventories. Of the region's 168 500 surface water bodies, the vast majority (86.5%) have a surface area of 5 ha or less (Fig. 3.B1).

Because most of the Atlantic region's small lakes are underlain by soils and bedrock having a low buffering potential, they are generally susceptible to acidification (Fig. 3.B2). Surface water bodies at high and moderate risk total over 121 000 (84%) for insular Newfoundland, 11 000 (86%) for Nova Scotia, and 10 000 (89%) for New Brunswick. Prince Edward Island's 1 100 surface water bodies, though they occur within sensitive environments, are considered well buffered because the waters are spring-fed from carbonate-rich groundwater. In total, over 142 600 surface water bodies, a major natural resource of Atlantic Canada, are both sensitive and exposed to acid stress.

Source: Environment Canada (1991).

FIGURE 3.B1

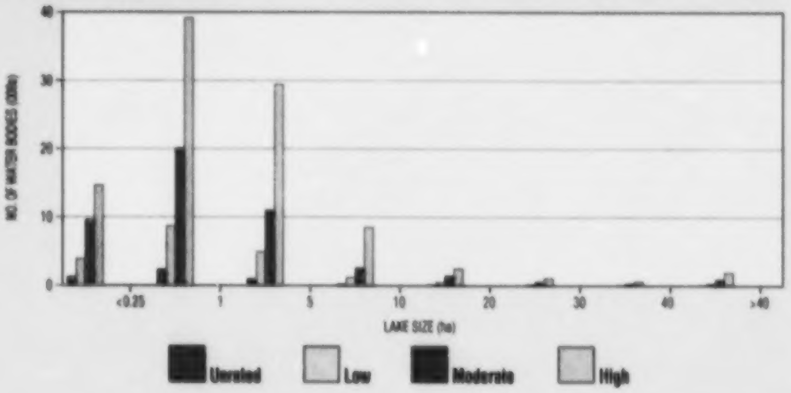
Number of surface water bodies in the Atlantic region



Source: Environment Canada (1991).

FIGURE 3.02

Surface water bodies in the Atlantic region: potential sensitivity to acid precipitation



Source: Environment Canada (1991).

NATURAL FACTORS THAT AFFECT WATER QUALITY

The quality of water varies naturally with season and geographic location, and this natural variation affects its suitability for human use and its response to disturbance. The legal definition of what constitutes "good water" varies according to its intended use, whether for drinking, swimming in, or as a healthy home for aquatic life, and is expressed in terms of its chemical, physical, and biological characteristics. Although some untreated water is of poor quality quite apart from any human-made pollution, Canada's most pressing water quality problems today are not due to natural factors.

Naturally occurring impurities

One measure of water quality familiar to most Canadian householders — hardness — illustrates the natural variability of water and its implications. The hardness of surface water varies across the country, according to the natural concentration of substances such as calcium, magnesium, sodium, potassium, bicarbonate, sulphate, and chloride. The concentrations of minerals in water can affect the numbers and diversity of aquatic life; the toxicity of some metals to fish, for example, increases with increased hardness. On the other hand, soft water has low buffering capacity, making it susceptible to acidification.

Although groundwater is generally of good quality for most uses, there are specific locations where the quality of natural groundwater is a problem. For example, areas in the Prairie provinces, parts of the Niagara escarpment, and portions of Nova Scotia and New Brunswick have groundwater that is so salty most plant species cannot tolerate it. Also, chemical constituents derived from mineral deposits are found in groundwater across Canada. Some of these, such as arsenic, fluoride, and uranium, are toxic. Other constituents — e.g., sulphides — cause acidic drainage, and some — e.g., iron — create taste problems.

Water quantity–quality interactions

Natural variation in flow levels also affects quality of water in complex ways. A river's capacity to dissolve or absorb pollutants, salts, and other solids is reduced under low-flow conditions. The quality of its water declines because there is less of it to dilute the contaminants that it does pick up, and because a higher proportion of the flow volume comes from groundwater, which generally contains more minerals. Low flow also means poorer quality fish habitat, because the water warms as ambient air temperatures rise. The opposite extreme is not necessarily better. During periods of heavy rain or snowmelt, runoff carries dissolved and suspended material into rivers. Thus, high-flow conditions, as well, can result in a reduction in water quality.

The water cycle

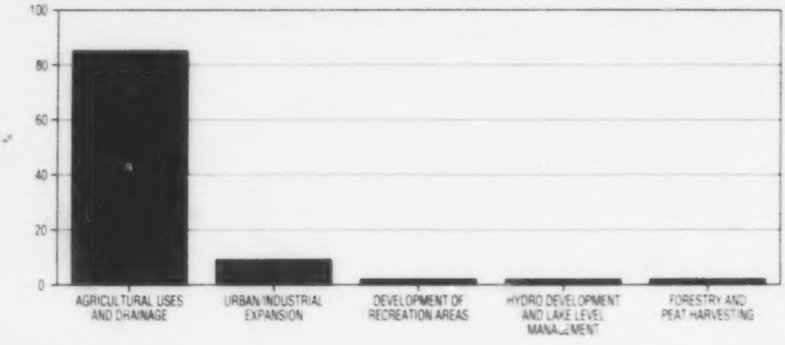
It is indeed a small world, a closed system, with limited ability to assimilate contaminants. Understanding the movement of water and contaminants through the biosphere, therefore, is critical.

Water is constantly in motion. It evaporates from the surface of land or water or is transpired from plants and moves into the atmosphere as water vapour, which, in turn, condenses and falls back to the surface as precipitation. Figure 3.1 shows the major components of this great recycling process, known as the water, or hydrologic, cycle.

As water moves through this cycle it transports, in addition to essential nutrients, contaminants harmful to the environment. The hydrologic cycle is global in scale. Through interaction with the land and atmosphere, it links widely separated regions, and in the process it spreads contamination throughout the environment. (Figure 24.7 shows this process for acidic deposition.) Contamination in arctic mammals and fish provides a dramatic example of this free trade of pollutants via the water medium. Precipitation and northern flowing rivers help to move contaminants to the Canadian Arctic from their far-off sources in southern Canada, the United States, the Soviet Union, Europe, and Asia (see Chapter 15).

FIGURE 3.2

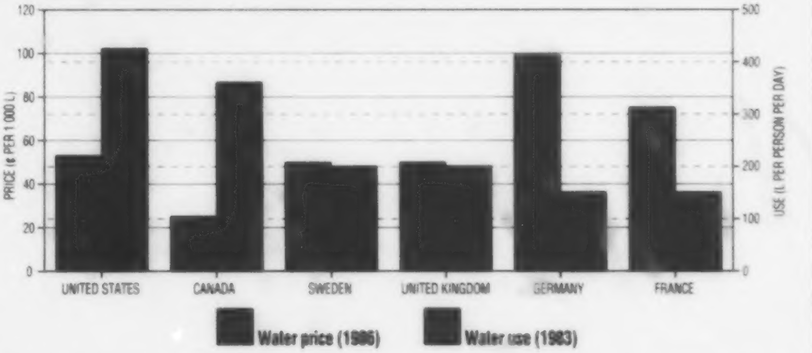
Causes of losses of freshwater and saltwater wetlands in Canada since European settlement



Source: Clarke *et al.* (1989).

FIGURE 3.3

A comparison of municipal water prices and use in selected countries



Source: Tate (1990).

USES OF FRESH WATER BY MAJOR ECONOMIC SECTORS

Every economic activity makes use of fresh water in some way. Water managers look at the direct uses of water — as coolant, cleaning agent, power source, and for drinking, irrigation, and diluting wastes — and classify them as to whether they are consumptive or nonconsumptive. There is a sense in which the technical terms "consumptive use" and "nonconsumptive use" mislead people into thinking that using water as a sewer for waste, or to turn turbines, or to cool steam that turned turbines, or for any other "nonconsumptive use" makes no demands on the environment, for no water is consumed. In fact, although the same amount of water may be returned to the water body that supplied it, some part of the aquatic ecosystem has probably suffered, or will suffer, because of the disruption in supply or a change in the quality of the water.

For too long, Canadians have accepted the discredited philosophy: "The solution to pollution is dilution." Even though it is now obvious that water bodies have limited capacity to absorb the impacts of waste discharged into them, rivers and lakes continue to be used as sinks for disposal of society's wastes. Some pollutants, such as municipal and industrial effluents, are discharged directly into the aquatic ecosystem and are referred to as point source pollutants. Other pathways — for example, urban and agricultural runoff and air deposition — are more diffuse and indirect and thus are considered non-point sources. Contaminants, whether deliberately or accidentally released, can enter water directly or indirectly. Although this distinction between point and non-point sources makes little difference from an overall ecosystem perspective, it is important from a prevention and management viewpoint.

When one considers an aquatic ecosystem as a whole and not just water as a resource, very few human activities are truly nonconsumptive. This section discusses uses of water by some key economic sectors and the ways in which they limit or preclude the availability of water for other uses.

Municipal use: swollen demands

Sustaining a reasonable quality of life requires about 80 L of water daily (Myers 1984). Canadians consume much more water than they need. In fact, they are the world's second largest water consumers, with an average household use of 360 L per person per day (Fig. 3.3). The fact that Canadians pay a much lower price for water than most of the world may encourage waste. For example, in Calgary, where water is not metered and people pay a flat rate per household, use is 60% higher than in Edmonton, where homeowners pay for water according to the volume they use.

In Canada, water withdrawn for municipal uses increased 49% from 1972 to 1986 and accounted for 11.2% of all withdrawals made in 1986 (Fig. 3.4). A large percentage (85% in 1986) of the water withdrawn is returned to the source lake, river, or aquifer.

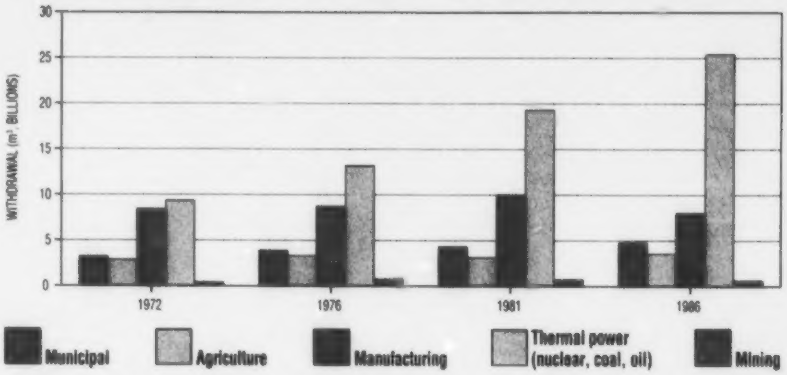
Most of the wastewater from municipalities is treated to varying degrees in a sewage plant before it is discharged. Primary treatment involves the mechanical removal of solid wastes. Secondary treatment is based on biological processes, by which bacteria degrade the bulk of dissolved organics. Finally, tertiary treatment is a chemical process designed to remove additional contaminants, such as nutrients, heavy metals, and inorganic dissolved solids.

The quality of the returned water varies depending on the level of treatment provided. Figure 3.5 shows improvements in levels of sewage treatment from 1983 to 1989 for Canadians residing in communities of over 1 000. The percentage of population receiving some form of municipal sewage treatment increased from 63% in 1983 to 70% in 1989. Quebec has recognized that a large proportion of the urban population without sewage treatment is in that province and is in the process of constructing treatment plants for all municipalities with populations over 5 000 by 1995.

Much of the effluent discharged directly into rivers is consumed by bacteria. In this process oxygen is depleted, so the effluent is said to have a biochemical oxygen demand (BOD). Dissolved oxygen in water is essential to most aquatic life. Therefore, the lower the degree of sewage treatment provided, the greater the BOD of the effluent and the greater the impact on the biological community of the receiving waters. Also, unless wastewater receives secondary treatment, disease-causing bacteria may be present in the effluent. The trend towards secondary and tertiary treatment of municipal effluent will lessen its adverse impacts on the aquatic environment. However, regardless of which type of sewage treatment is provided, the ability of these processes to remove toxic substances is not yet proven.

FIGURE 3.4

Total water withdrawal in Canada in 1972, 1976, 1981, and 1986

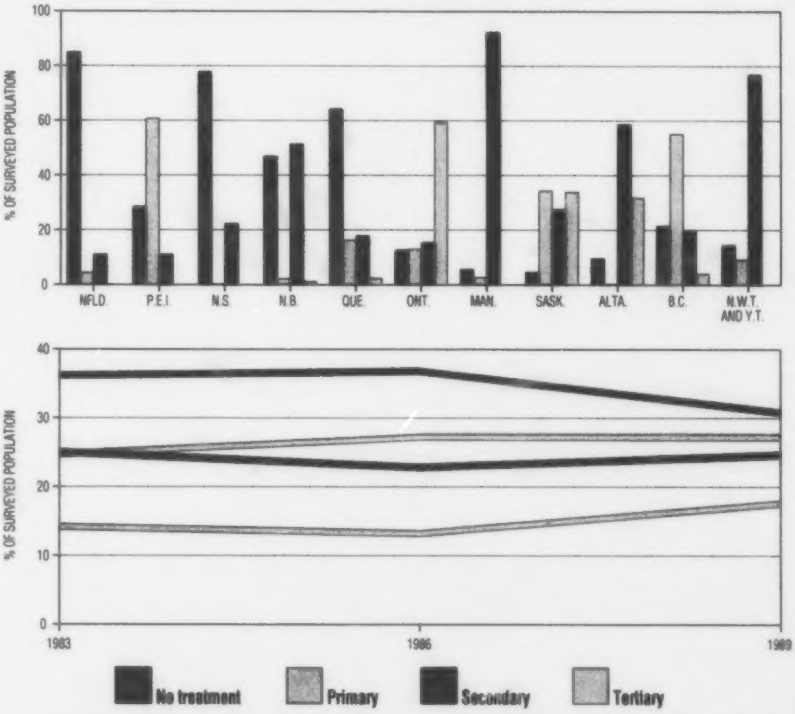


Source: Tate and Scharf (in press).

FIGURE 3.5

Percentage of population served by primary, secondary, and tertiary sewage treatment in communities over 1 000

Data are by province in 1989 (top figure) and for Canada in 1983, 1986, and 1989 (bottom figure).



Source: Environment Canada (1990*d*).

Agricultural use: a thirsty sector

Agriculture has been singled out as a "particularly thirsty" sector of the economy (Myers 1984). But of the five key economic sectors, in 1986, agriculture ranked fourth in water withdrawal, accounting for 8.4% of the total water intake in the country. However, in contrast to the municipal sector, only 30% of the water withdrawn for agricultural use is returned to its source.

Irrigation is the big water user on the farm. In 1970, 421 357 ha were under irrigation across Canada. By 1985, this figure had risen to 747 625 ha (Fig. 3.6). Over 90% of irrigation in Canada occurs in the west, notably in Alberta, which alone accounts for over 60% of all irrigated land in Canada.

Irrigation affects water quantity and quality in a variety of ways. Diverting water to the land reduces river flow and changes the river's temporal pattern of flow. As well, water returned to the rivers via irrigation channels and field runoff carries fertilizers, pesticides, salts, and sulphates. Return flows, with concentrations of total dissolved solids up to double what they were before irrigation, lower the overall quality of water for aquatic life. This has been demonstrated in the South Saskatchewan River basin (Hamilton and Wright 1985) and in the Bow and Oldman rivers (Hamilton *et al.* 1982).

In some cases, less than a third of the water withdrawn from a stream actually reaches the plants, due to such problems as leaking pipes and joints, evaporation, and seepage from ditches. Improved efficiency of the existing irrigation systems would reduce the impact of irrigation on the environment.

Irrigation is forecast to increase in certain areas of Canada. For example, by the year 2020, the demand for irrigation water from Lake Diefenbaker, Saskatchewan, is expected to rise to two and one-half times the 1981 levels. A major issue faced by water managers in the Prairie provinces is the allocation of a large proportion of the water supply to irrigation as opposed to other uses. When limited water supplies are used for irrigation, other uses of social, environmental, or economic value are foregone. Weighing the costs and benefits of irrigation is further complicated by the fact that those who benefit most directly — primarily farmers themselves — do not bear the true cost of supplying water. Indeed, the provinces pay an average of 85% of the total monetary cost of supplying water for irrigation. Subsidized irrigation often has a snowball effect, leading to increased agricultural expansion, which, in turn, places further demands upon limited supplies.

BOX 3.2

Agricultural pesticides and groundwater

One in every four Canadians relies on groundwater for domestic supply, and over 85% of the water consumed by livestock comes from the ground (Hess 1986). Pesticide contamination has been found in wells from Prince Edward Island to British Columbia. In most cases, it is difficult to determine whether contamination is from spills or other accidents or from the pesticides leaching to the groundwater through normal use. Agricultural pesticides detected in groundwater include aldicarb residues, picloram, alachlor, chlorothalonil, carbofuran, and 1,2-dichloropropane (Gillis and Walker 1986; Krawchuk and Webster 1987). In addition, other broadly applied substances, such as fertilizers, have also found their way into groundwater. The potential for contamination of surface water exists where groundwater emerges at the surface (e.g., springs, groundwater contribution to streamflow).

Many factors influence how likely a pesticide is to contaminate groundwater. A pesticide that breaks down quickly or vaporizes readily is less likely to leach into the soil. The characteristics of the soil in the area where the substance is applied and the amount and type of precipitation help to determine whether the pesticide reaches the water table. Finally, of course, variables associated with pesticide use, such as timing and rate of application, also have to be considered. By taking all these factors into account whenever pesticides are applied, the likelihood of groundwater contamination can be minimized.

Recently, some initial studies that aim to provide information and tools for groundwater protection have been completed in Canada. As part of a national investigation, McRae (1989) produced a series of 1:2 000 000-scale maps for southern Canada showing areas vulnerable to groundwater contamination. These areas were identified on the basis of key characteristics of the overlying soil and landscape. In another study, Turner (in press) developed a model of groundwater vulnerability using information on soil texture and land use for a 30 000-km^2 area in southeastern Saskatchewan and southwestern Manitoba. Using a geographic information system, Turner superimposed maps portraying soil types on maps of land use to derive the vulnerability maps (Fig. 3.B3).

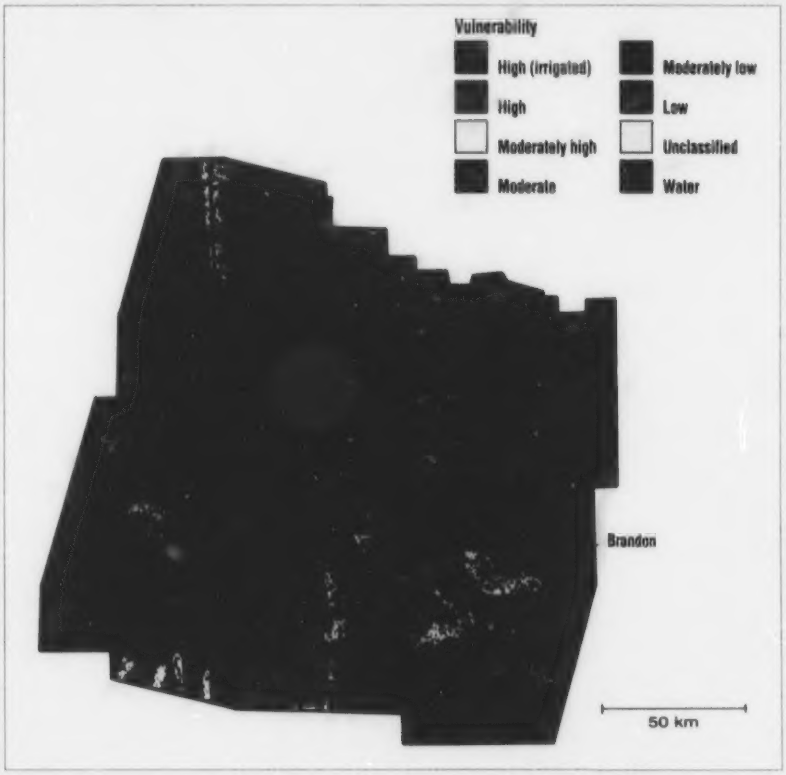
These initial studies illustrate the potential of maps that show vulnerability to groundwater contamination: they allow resource managers to screen large areas, "homing in" on zones of potential concern, where monitoring (e.g., well water sampling) can be focused to determine if groundwater contamination exists. They could also help regulatory agencies identify areas where the use of selected pesticides should be restricted. Despite their promise, at present such techniques must be regarded as experimental. One major hurdle that will have to be overcome is the potential for misunderstanding of the significance and misuse of the information on such maps. Although they may be valuable supplements and tools, such maps will never replace expert judgements.

It can be argued that dam construction and diversion works related to irrigation uses have made important contributions to regional economic development. Increasingly, however, new projects are subject to scrutiny,

FIGURE 3.[illegible]

Vulnerability to groundwater contamination near Brandon, Manitoba

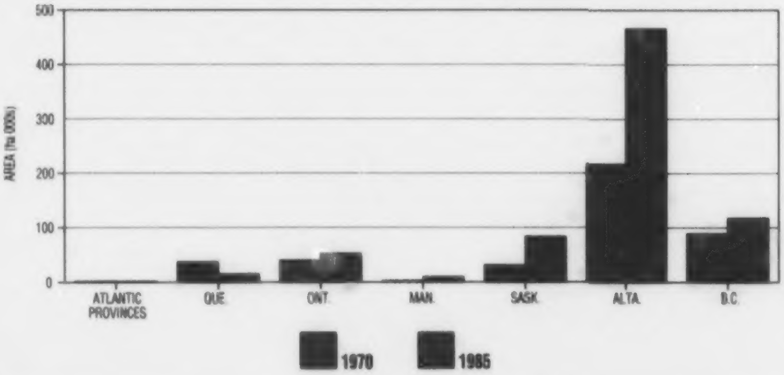
The most vulnerable 0.04% of the nearly 30 000 km² shown on the map lies just east of Brandon, where an area with sandy soils is used as irrigated cropland. The 5% of the area shown as "high" and "moderately high" is also cropland on sandy soils, but without irrigation.



Source: Turner (in press).

FIGURE 3.6

Area of land irrigated in Canada, by region, 1970 and 1985



Source: Statistics Canada (1973, 1987).

public debate, and litigation due to their potential to cause adverse environmental impacts. Evidence of this can be seen in the recent controversy surrounding dam construction on the Oldman River in Alberta and the Rafferty–Alameda project in Saskatchewan. As well, the governments of Canada and Manitoba opposed the original North Dakota Garrison Diversion project, and it was rejected by the International Joint Commission, because of the possible introduction of foreign fish species, parasites, and diseases that might have threatened the Lake Winnipeg commercial and recreational fisheries.

Across Canada, 243 active ingredients, in about 1 250 commercial products, are used as pesticides on agricultural crops. Although a large proportion of these pesticides either break down quickly or are retained in the soil, some, unfortunately, find their way into lakes and streams by a variety of pathways — runoff, soil erosion, air deposition, and through careless use or disposal, and some seep into groundwater (see Box 3.2 and section entitled "Pesticides").

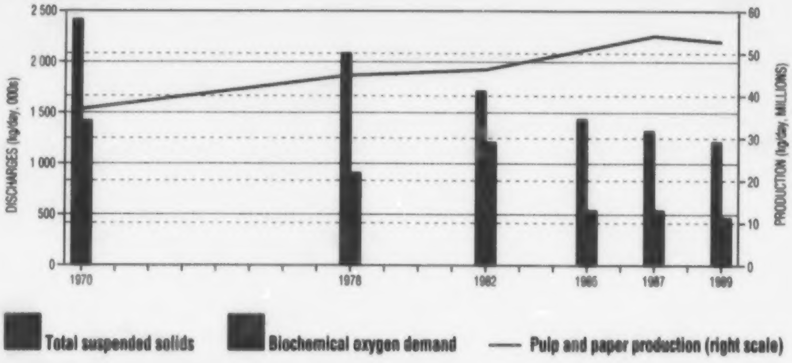
Chemical fertilizers used in agriculture readily dissolve in water and find their way, through surface runoff and percolation, from agricultural land into lakes and rivers, where they cause eutrophication (see Chapter 18). Manure from dairy and livestock feedlot operations can also contribute to nutrient loading of surface water and groundwater, increasing BOD and promoting eutrophication.

Industrial processes: cleaning up their act

Few — if any — industries do not use water in their manufacturing processes. Water is used in a variety of ways — for incorporation into products, and for flushing, cooling, cleaning, and dilution of wastes. According to Figure 3.4, all economic sectors showed an increase in water withdrawal from 1972 to 1986 with the exception of the manufacturing sector, which actually showed a 5% decrease for this period. The reason for this anomaly is unclear. It may indicate

FIGURE 3.7

Discharges of total suspended solids and biochemical oxygen demand to fresh water from the Canadian pulp and paper industry, 1970–89



Source: Environment Canada, Industrial Programs Branch.

a shift to water-conserving processes or it may be a reflection of other factors (i.e., economic trends). Future surveys should confirm the direction of the shift.

Industry, in general, is the source of many substances that are contaminating the aquatic environment: mercury, sulphur via acidic deposition, various chlorinated organic compounds such as PCBs, PAHs, and sediments — to name a few. A more detailed discussion of some of these contaminants and their effects on the aquatic environment is given later. A brief review of the impact of water use by selected industrial sectors follows.

Mining

The mining industry withdraws little water compared to other economic sectors, but the industry increased its withdrawal by 64% between 1972 and 1986. Despite its comparatively low rate of withdrawal, the impact of the mining industry's use of water cannot be overlooked. Mining operations often reuse water many times for flushing materials. The process water, when released, typically contains residues of the original ore and other waste minerals as well as small quantities of reagents, many of which are highly toxic. Although the used water is usually held in tailings ponds before discharge into a receiving water body, leakage from such impoundments into groundwater and surface water is sometimes a problem. Underground mining and open pit operations often result in acid production. For example, sulphide-bearing metallic ore may oxidize to produce sulphuric acid, resulting in highly acidic conditions and high metal concentrations in receiving waters.

Collectively, various stages of mining operations may result in a variety of detrimental effects on water quality and the aquatic environment. These include sedimentation and turbidity; increased concentrations of heavy metals, especially cadmium; increased acidity followed by mobilization of metals; introduction of reagents, including sodium cyanide, orthocresols, cresols, and cresylic acid; and the discharge of petroleum products.

Pulp and paper

Canadians concerned about clean water are focusing their attention to a greater degree than ever before on pulp and paper operations. Effluent from pulp and paper mills includes solid waste and chlorinated organic chemicals, such as dioxins and furans, which are by-products of the chlorine bleaching process. All of these substances can have detrimental effects upon the aquatic ecosystem. As it decays, organic matter can exhaust the oxygen supply in water, making it unfit to support oxygen-breathing organisms such as fish. But it is chlorinated organic compounds, especially dioxins and furans, that are of particular concern because of their propensity to bioaccumulate.

Many companies are replacing chlorine bleach with chlorine dioxide and hydrogen peroxide in their fine-paper bleaching process, which greatly reduces the formation of dioxins and furans. Government regulation has also played a role in reducing the environmental impacts of the pulp and paper industry. Figure 3.7 shows that levels of BOD and total suspended solids in discharges from the pulp and paper industry have generally decreased since 1970. Regulations for such discharges were instituted in 1973 under the federal *Fisheries Act*. These regulations are currently being revised with the aim of virtually eliminating dioxin and furan discharges.

Petroleum industry

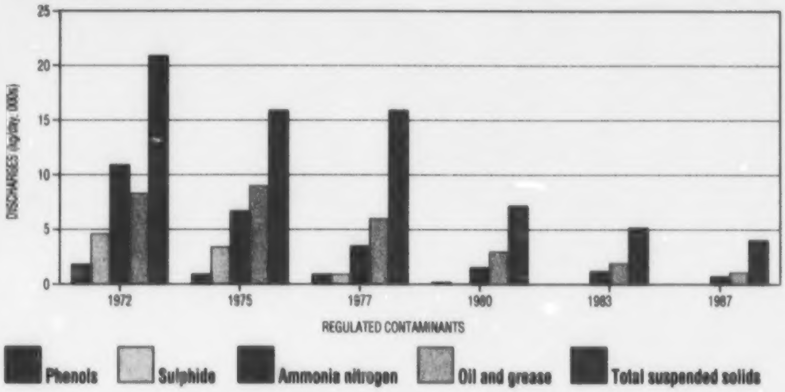
The Canadian petroleum industry has dramatically reduced its liquid discharge of sulphides, phenols, ammonia nitrogen, oil and grease, and total suspended solids since 1972 (Fig. 3.8). This sizable reduction in the release of petroleum-related hazardous contaminants to waterways is largely attributable to the effluent regulations and guidelines instituted under the federal *Fisheries Act* in 1973.

Reducing industrial toxic waste

Reducing the discharge of industrial toxic waste from all sources requires concerted and cooperative effort by all levels of government and by industry. The St. Lawrence Action Plan is a step in this direction. The federal and Quebec governments have identified 50 industrial establishments on the St. Lawrence and have agreed on a target of 90% reduction of liquid toxic wastes released from these plants by 1993. Twenty of these industries are now controlled through regulations. Other priority industries not currently subject to regulation are

FIGURE 3.8

National net discharges of liquid waste[a] by the Canadian petroleum industry, 1972–87



[a] For substances for which regulations exist; net loadings represent annual average.

Source: Environment Canada, Industrial Programs Branch.

establishing cleanup plans designed to meet the 90% reduction target. As of May 1991, 22 of the 30 unregulated industries had signed official cleanup agreements with the Quebec Ministry of Environment.

A program in Ontario, the Municipal/Industrial Strategy for Abatement (MISA), has been initiated to reduce water pollution from industries and municipalities. The MISA program currently involves the municipalities and nine major industrial sectors. Monitoring regulations now in place for the nine industrial sectors require dischargers to measure the types, concentrations, and total amounts of toxic substances present in their effluents. This information will be used in the future to formulate abatement regulations.

In addition to these initiatives, the forestry, metallic and nonmetallic mining, pulp and paper, and chemical industry associations established environmental codes of practice in the late 1980s, which include prudent and nonpolluting techniques for water use. Compliance with these codes, however, is voluntary.

Thermal and hydroelectric power generation: a lion's share

The energy sector of the economy is Canada's biggest water guzzler. In 1986 about 80 thermal electric plants in Canada, including 18 nuclear plants, used a staggering volume of water — equivalent to 1 300 hours of continuous flow over Niagara Falls.

The World Commission on Environment and Development (1987) concluded that the ultimate limits to global development are perhaps determined by the availability of energy resources and by the biosphere's capacity to absorb the by-products of energy use. Thermal (nuclear, coal, oil) and hydroelectric power generation have significant effects on Canada's water. Thermal power generation accounted for 60% of total withdrawals and has increased withdrawals by 172% between 1972 and 1986. Newly commissioned nuclear plants in Ontario were responsible for most of this increase.

Most water used for steam generation and cooling is returned to the source lake or river. Though water quantity may not be depleted, all thermal electric power generation affects water quality by raising the temperature of the receiving water, notwithstanding the use of cooling ponds. Increased water temperature, so-called heat pollution, can harm aquatic species, such as trout, which require colder water. Higher water temperatures can also increase evaporation. For small receiving water bodies, such as the Boundary Reservoir on Long Creek in the Souris basin, Saskatchewan, evaporation loss eventually may increase salt concentration to unacceptable levels.

The energy sector also contributes its share of contaminants to the aquatic environment. Coal-fuelled thermal plants add considerably to the acidic deposition problem because of their sulphur emissions. Nuclear-fuelled thermal electric plants could affect Canada's aquatic environment through radioactive waste leakage, although no significant event has occurred to date. Uranium contamination of surface water and groundwater is also possible where uranium is refined and disposed of after use.

Falling water, or hydro power, is Canada's most important source of electricity, a fact underlined by a recent inventory that lists 613 large dams and 54 interbasin diversions in Canada (Table 3.1). Falling water generated over 62% of the electricity produced in this country in 1988. It is forecast that by the year 2005, hydroelectric production could increase by 26%.

The downside to dams

Hydroelectricity has often been promoted as an "environmentally clean" energy source with inherent advantages over nuclear and fossil fuel sources. But the construction of dams to hold back streamflow for year-round hydroelectricity causes large-scale changes to aquatic and terrestrial ecosystems, including reduction in habitat for plants and animals that require fast-flowing water and inundation of valley lands valuable to agriculture and wildlife. The

TABLE 3.1

Dams and interbasin diversions in Canada

	Dams			Diversions		
Jurisdiction	No. of large dams	Gross storage capacity (10^9 m^3)	% of capacity for hydro	No. of interbasin diversions	Average annual flow rates (m^3/s)	% of flows for hydro
Newfoundland	79	76.7	100	5	725	100
Nova Scotia	35	1.3	93	4	18	100
Prince Edward Island	–	–	–	–	–	–
New Brunswick	16	1.4	95	2	2	27
Quebec	189	393.9	98	6	1 854	100
Ontario	79	54.9	73	9	564	89
Manitoba	34	75.9	99	5	773	97
Saskatchewan	38	30.7	77	5	30	85
Alberta	48	5.8	63	9	67	22
British Columbia	89	176.2	95	9	367	89
Northwest Territories	3	0.3	100	–	–	–
Yukon Territory	3	–	100	–	–	–
Canada	**613**	**817.1**	**95**	**54**	**4 400**	**96**

Source: Canadian National Committee of the International Commission on Large Dams (1984); Quinn (1990).

flooding of organic matter may result in a lack of dissolved oxygen in the water, with significant repercussions for the flora and fauna of aquatic ecosystems. Furthermore, a series of biochemical reactions are induced by the absence of dissolved oxygen at the sediment–water interface, one of which is the methylation of naturally occurring inorganic mercury, by microbes that thrive in the presence of drowned organic matter, into biologically available, toxic methylmercury compounds, resulting in its subsequent incorporation into the aquatic food web (see Box 3.3). In addition, reservoir water levels are normally managed to optimize electric power production, which does not always meet other requirements of the natural system, such as waterfowl breeding and fish migrations.

Hydroelectric developments offer both benefits and costs to other water users. Recreational and commercial fisheries have been established on some reservoirs, but hydro development has destroyed other fisheries. Often it has been aboriginal people who have been most detrimentally affected by hydro projects. Such developments have meant that traditional subsistence communities have had to make abrupt transitions to different lifestyles, often with tragic social consequences.

Transportation: subtle ways

Navigation affects water ecosystems in many subtle ways. Ship traffic causes bank erosion, disturbs bottom sediments, and requires dredging to keep waterways navigable. Ships and boats spill hazardous materials into aquatic ecosystems, and even ice-breaking poses a threat to fish and wildlife (Pearse *et al.* 1985).

Often ships carry not only freight but also clandestine passengers in their ballast waters. A recent case in point is the zebra mussel, which is thought to have arrived from Europe in ballast water that was discharged from ships into Lake St. Clair. Eventually, these fast-multiplying mussels are expected to invade all of the Great Lakes and inland waterways connected to them (Lewis 1990). This latest Great Lakes exotic has the potential to cause widespread economic and ecological calamity (see Chapter 18).

Recreation: the spirit of water

"What is increasingly lacking are places for solitude [which are] restorative to the spirit. And water attracts people for that reason — they come to feel calmed by the water. It's a universal human trait. A large expanse of water is healing." Canadian journalist June Callwood told the Royal Commission on the Future of the Toronto Waterfront in 1989.

Most Canadians participate in some type of water recreation, be it swimming, fishing, skating, canoeing, or just sitting by a lake. Some Canadians seek the remoteness of northern lakes and parks, but most urban residents rely on rivers, lakes, and reservoirs in or near cities. City dwellers are finding it harder to find good water recreation sites close to home, however, as water quality declines and urban development limits access.

Guidelines for Canadian Recreational Water Quality, produced by Health and Welfare Canada (1983), are used by provinces and municipalities to set standards that ensure that there is negligible risk to the health and safety of Canadians. These guidelines are based on limits for fecal coliforms and pathogenic microorganisms; surveys of potential sources of contamination such as inadequately treated sewage, hazardous substances, and stormwater runoff; and studies by health authorities of potential water-borne infections.

Using these guidelines as a means to assess risk of infection in their communities, a number of cities have had to close their beaches from time to time. For example, in August 1987, all Toronto beaches on Lake Ontario were posted as unfit for swimming because of the risk to health caused by pollution (Science Council of Canada 1988). Similarly, Trout Lake in the Vancouver area was closed for most of 1989 due to potential health risks.

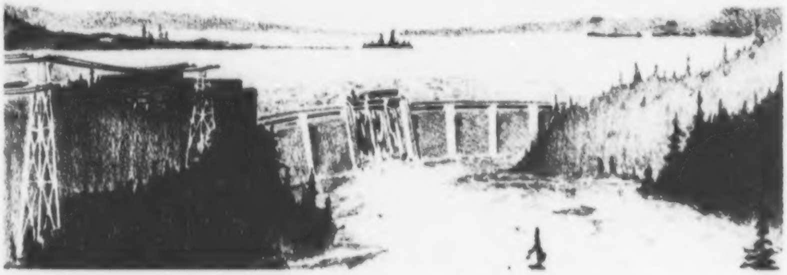
Pollution from combined and storm sewers is most often the cause of beach closures. Combined sewers, which still

BOX 3.3

Major hydro developments in Canada

Hydroelectric project construction in Canada accelerated in the 1960s, following a change in federal policy towards longer term export arrangements. Major projects included the W.A.C. Bennett dam (1967) on the Peace River and the Mica dam (1972) on the Columbia River in British Columbia; the Churchill Falls project (1971) in Labrador; the Lake Winnipeg Regulation and Churchill- Nelson Diversion (1976) in Manitoba; and La Grande project (Phase I, 1983) in the James Bay region of Quebec.

The downstream effects of changes in the flow regime were dramatically illustrated on the Peace-Athabasca delta following the construction of the W.A.C. Bennett dam. Disruption of the annual flooding of the delta initiated the conversion of wetlands to less-productive terrestrial habitats. It was during follow-up studies on the effects of the Churchill-Nelson project that the link between elevated mercury levels and impoundment was first discovered. Increased levels were due to the mercury methylation process brought on by flooding organic matter. Elevated mercury levels have since been noted elsewhere. For example, the major known impact of Phase I of La Grande project in Quebec was the triggering of a four-to sixfold increase in fish mercury concentrations within the reservoirs.



exist in many older parts of Canadian cities, carry both sanitary sewage and stormwater runoff. Usually, the combined sewers deliver sanitary sewage to a treatment plant. During large storms, however, discharge of combined sewers surges, and the sewer pipes fill to the point where the water volume cannot be accommodated by treatment plants. At such times, both the sanitary sewage and storm runoff flow untreated directly into receiving streams — and eventually hit the beach.

Although recreation is often restricted because of pollution, recreational activity itself can also degrade the aquatic environment. High densities of swimmers at beaches can increase bacterial levels over the short term. Power boating may result in spills of gasoline and crankcase oil. Boating may also lead to erosion along lake shores and river banks, causing turbidity and disruption of aquatic communities. Cottage septic tanks sometimes leak their contents into nearby lakes and rivers.

These types of problems have led to the increasing use of legislation and local bylaws to regulate power boating and nearshore cottage development. One example is the more widespread enforcement of the boating restriction regulations under the *Canada Shipping Act*. Quebec, British Columbia, Alberta, Manitoba, Nova Scotia, and Ontario municipalities have all used this law to impose boating restrictions on some of their water bodies.

NUTRIENTS IN WATER: TOO MUCH OF A GOOD THING

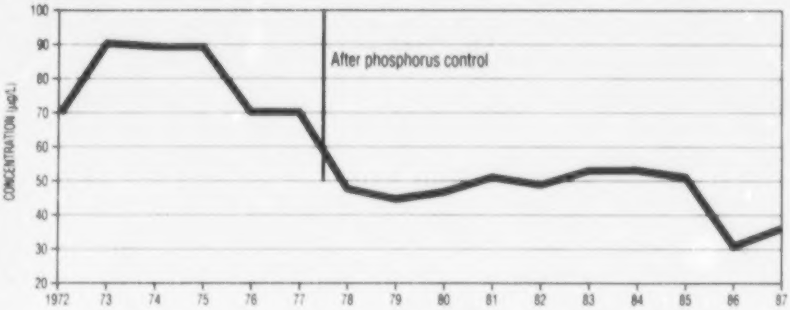
A minimum concentration of nutrients, especially phosphorus and nitrogen, is necessary for plant production in aquatic ecosystems. An oversupply, however, leads to an algal bloom, characterized by a massive "greening" of the water column. In an advanced stage, eutrophication — as this process of uncontrolled plant growth is called — can destroy the biological community of lakes and rivers, ruin the recreational value of a water body, and increase the cost of drinking water treatment.

Municipal and industrial effluents and runoff from agricultural areas (including dairy and livestock operations) are major contributors of phosphorus and nitrogen to the aquatic ecosystem. Beginning in the 1970s, programs were implemented under the *Canada Water Act* to limit the phosphorus content of detergents. Also, sewage treatment was upgraded, particularly in the Great Lakes region, to reduce phosphorus in municipal effluents. As a result, the rate of eutrophication of water bodies began to slow. After 10 years of control, levels of phosphorus in the Bay of Quinte have dropped by nearly half (Fig. 3.9). In response, phytoplankton density, a good indicator of excess phosphorus concentrations in water, has dropped significantly as well. Reducing point sources is only half the battle, however. The contribution of non-point sources of phosphorus to the Great Lakes is now much larger than the contribution of point sources and will require similarly concerted action. At the same time, nitrate-plus-nitrite concentrations have been increasing. It is feared that if phosphorus controls are relaxed, excess nitrogen now in the system could initiate another round of serious eutrophication (see Chapter 18).

Despite success in reducing phosphorus loadings in many areas of Canada, nutrient enrichment of rivers and lakes on the prairies is still a widespread problem. Researchers are finding that,

FIGURE 3.9

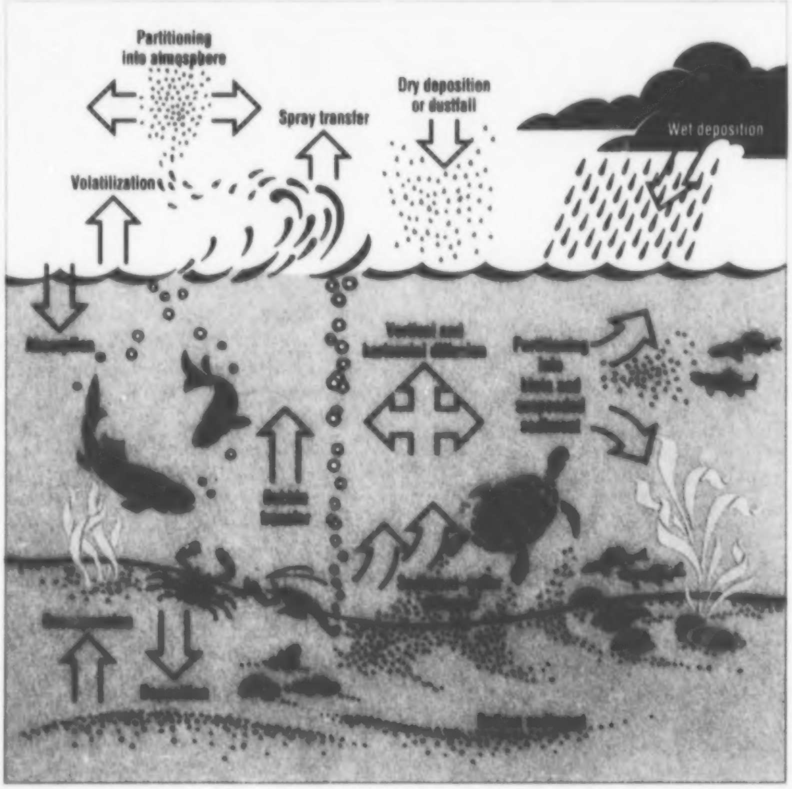
Total phosphorus concentration, Bay of Quinte, before and after phosphorus control



Source: International Joint Commission (1989).

FIGURE 3.10

The movement of toxic substances in the aquatic environment



Source: Environment Canada (1990a).

although phosphorus concentrations are down, the expected decrease in aquatic weeds and algal blooms has not always followed. For example, Regina reduced its phosphorus load by 80% and feedlot operations were moved away from streams or lakes, with little improvement to the Qu'Appelle lakes. A similar situation has been described for the Thompson River near Kamloops (Bothwell *et al.* 1989) and for the Bow River downstream of Calgary (Charlton and Bayne 1986). One explanation for this phenomenon is the internal recycling of phosphorus, whereby, when there is a lack of dissolved oxygen in the water, phosphorus held in sediments dissolves and becomes available for further aquatic plant growth (Chambers *et al.* 1989).

SELECTED TOXIC CONTAMINANTS

Between 1968 and 1972, the dumping of used waste oils, mainly from the chemical and petrochemical industries, polluted the groundwater between the towns of Mercier and Ste-Martine, Quebec. Wells were contaminated. Unbeknown to them, residents were exposed to health risks, and after a $10 million expenditure, the water in 1986 was still undrinkable (Science Council of Canada 1988).

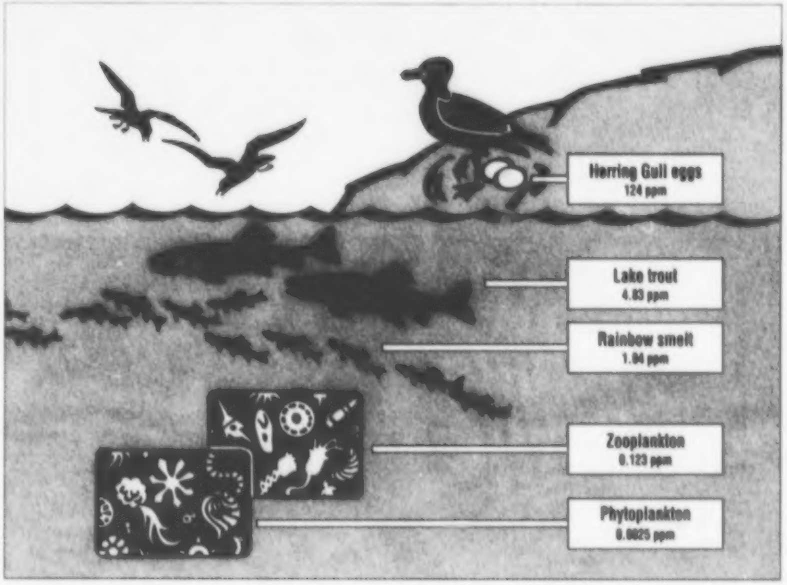
A vast number of contaminants enter fresh water because of human activity. Many of these substances are capable of causing harm to the environment or human life, and, therefore, they are defined as toxic under the 1988 *Canadian Environmental Protection Act.*

A substance is "acutely" toxic if it acts quickly to produce short-term lethal or sublethal effects. Or, it may exhibit "chronic" toxicity, if it takes a relatively long time to cause changes to metabolism and reproduction, or mutations and death. Some substances induce both acute and chronic effects in organisms.

A toxic substance is persistent or nonpersistent in the environment depending on how long it takes to break down. Both persistent and nonpersistent contaminants can be harmful to the aquatic

FIGURE 3.11

Bioaccumulation and biomagnification of PCBs in the Great Lakes aquatic food chain



Source: Environment Canada *et al.* (1987).

environment, in varying degrees, depending upon their amount and source. Nonpersistent, acutely toxic substances can "shock" the biota of rivers and lakes, suddenly killing or severely stressing both fish and plant life. However, persistent substances have the potential to cause both acute and chronic problems and can affect the ecosystem long after the source of the pollution has ceased to exist.

However they originally entered the aquatic environment, whether through point or non-point sources, whether they are released accidentally or applied deliberately, persistent substances spread throughout it and impair other parts. Figure 3.10 shows the pathways of toxic substances as they cycle within, out of, and back into the water.

Aquatic organisms may take up toxic contaminants from surrounding waters directly through their surfaces, through respiration or ingestion of water, or through consumption of food containing chemicals. If an organism's intake of a long-lasting contaminant exceeds its ability to metabolize or eliminate the substance, the chemical accumulates over time within its tissues. This insidious process is known as bioaccumulation. At the same time, concentrations of such bioaccumulated substances are progressively magnified at higher levels of the food chain — a phenomenon known as biomagnification. Although the concentration of a contaminant may be virtually undetectable in the water, when it passes up the food chain from prey to predator it may be magnified hundreds or thousands of times by the time it reaches predator fish. Further concentration occurs when wildlife, domesticated animals, or people eat the fish. Figure 3.11 shows the biomagnification of a family of persistent toxic substances, PCBs, within the aquatic food chain.

As well, the phenomenon of synergism, whereby exposure to a mixture of toxic substances can have a greater effect than the sum of the effects of exposure to each substance individually, may be cause for concern. Potential synergistic effects take on greater significance as, to date, 362 chemical contaminants have been detected in the Great Lakes ecosystem (International Joint Commission 1987). Although synergistic effects in fresh water are not well understood, evidence from laboratory studies points to potential dangers. For example, a mixture of the pesticide malathion and EPN (ethyl paranitrophenyl phenylphosphonothioate) was almost three and a half times more toxic to pheasant and quail chicks than expected, based on the toxicity of each chemical separately (Kreitzer and Spann 1973). Even the addition of a nontoxic substance to a toxic substance can produce synergistic effects. Hoffman and Albers (1984) found that pesticides mixed with nontoxic oil were up to 18 times more toxic than when mixed with water.

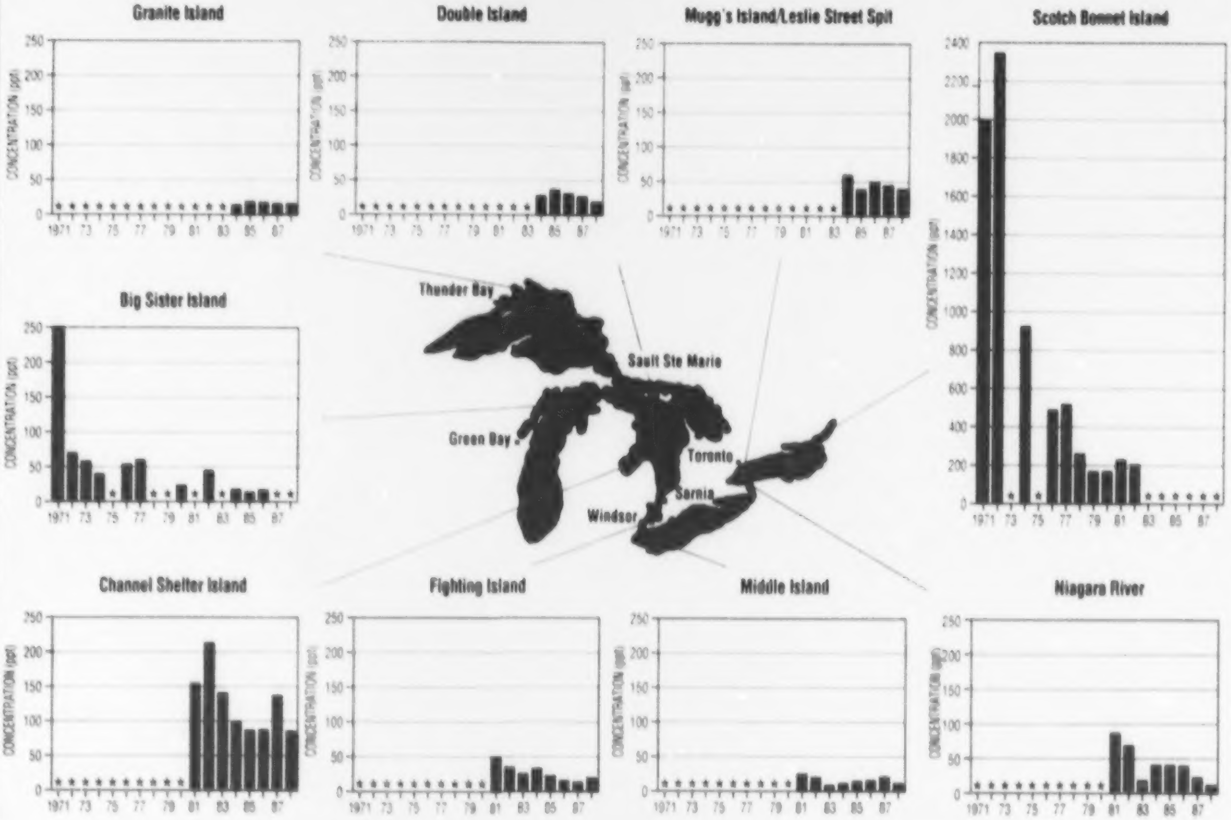
The health of aquatic ecosystems ultimately affects human health. Although the link between ecosystem health and human health is complex and not well understood, people cannot help but be concerned when they observe the symptoms of an ailing ecosystem. Fish with tumours and diseases caused by toxins in water, birds with crossed bills and other deformities caused by eating contaminated fish, and reproductive failures in mammals feeding on the top predators of the aquatic food web (see Chapter 18) all suggest that human health may be in jeopardy. The following sections provide information on the sources of specific toxic substances and their effects on ecosystem and human health.

Dioxins and furans

No class of contaminants has caused more concern in recent years than dioxins, largely because of their potential to cause effects in almost unimaginably small quantities. In laboratory testing, mortality in rainbow trout, for example, occurs at concentrations of 2,3,7,8-TCDD (a dioxin) as low as 40 parts per quadrillion (Mehrle *et al.* 1988) — an amount equal to a thimblefull of dioxin in 50 000 Olympic-sized swimming pools.

FIGURE 3.12

Concentrations of 2,3,7,8-TCDD in Herring Gull eggs in the Great Lakes



*Indicates no data.

Source: Bishop and Weseloh (1990).

Dioxins (polychlorinated dibenzodioxins), together with furans (polychlorinated dibenzofurans), constitute a family of 210 chemically related chlorinated organic compounds, some of which are extremely toxic to laboratory animals (Department of Fisheries and Oceans 1990). Toxicity varies with both the number and the placement of the chlorine atoms on the molecule. Of particular concern are 2,3,7,8-TCDD and 2,3,7,8-TCDF (Boddington *et al.* 1990). These compounds are highly persistent, with a high potential for accumulating in living tissue. The major sources of dioxins and furans are commercial chemicals (pesticides and wood preservatives containing chlorophenols); incineration of chlorine-containing substances; pulp and paper mills that use chlorine bleaching; and both accidental fires and spills involving PCBs, which contain principally furan contaminants (Boddington *et al.* 1990).

Biomonitoring — the use of biological indicators to test for the presence of pollutants in the environment — has indicated that dioxins may have contributed to reproductive failures in a Great Blue Heron colony in British Columbia (Elliott *et al.* 1989). The colony was located on the Strait of Georgia about 1 km from a kraft pulp mill that was the main source of the dioxin 2,3,7,8-TCDD in local waters. When, in 1987, the mean concentration of 2,3,7,8-TCDD in embryos jumped from 66 ppt to 210 ppt, the colony failed to produce any young that fledged.

The trends in average annual concentrations of 2,3,7,8-TCDD in Herring Gull eggs monitored at nine colonies on the Great Lakes indicate a decline in this contaminant over the period 1970–88 (Fig. 3.12). Elevated levels of the dioxin 2,3,7,8-TCDD are linked to some types of chemical production and combustion involving chlorine and to effluents from the production and disposal of the herbicide 2,4,5-T. The discontinued production of this herbicide in the mid-1970s at a plant near Saginaw Bay, Michigan, and another in Niagara Falls, New York, is a major reason for the decline in this contaminant (Bishop and Weseloh 1990).

Dioxins and furans have been found in sediments and biota of waters downstream from pulp and paper mills using chlorine bleaching. All provinces, except Manitoba, P.E.I., and Newfoundland, have at least one such plant. Although neither territory has kraft mills, the contaminants may be introduced into N.W.T.'s aquatic ecosystem by water flowing north. For example, development of kraft mills along the Peace–Athabasca River system appears to have introduced dioxins into the waters flowing into the Slave River.

In British Columbia, a number of commercial fishing areas were closed by federal authorities because of contamination with dioxins and furans from upstream pulp and paper plants. In May 1989, health advisories were issued by the federal and provincial governments on the consumption of certain freshwater fish caught near inland pulp mills in British Columbia. Also, in April 1990, Health and Welfare Canada recommended restricting consumption of walleye from the Mistassini River near St. Félicien, in the Lac St. Jean area, and brown bullhead in the St. Maurice River near La Tuque because of contamination with dioxins and furans.

Studies of human populations exposed to dioxins and furans indicate that short-term exposures to several milligrams of a mixture of these compounds can lead to a variety of effects on skin, eyes, and sensory and behavioural functions. Although generally reversible, it may take several years for symptoms to disappear. The exposure of women to high levels of furans in contaminated rice oil in Japan and Taiwan may have been responsible for reproductive anomalies and infant mortalities. Evidence linking exposure to dioxins and furans to excess cancer in human populations is inconclusive and conflicting (Boddington *et al.* 1990).

Although dioxins and furans are found in fish and other aquatic organisms due to biomagnification, the extremely small concentrations in drinking water are not thought to be harmful to humans. A recent Canada–Ontario study (Birmingham *et al.* 1989) estimated that between 94 and 96% of the intake of dioxin and furan compounds by non-smoking adults is from food. The remainder is received equally from water, air, and soil.

For contaminants that are both persistent and highly fat soluble, such as dioxins and PCBs, there is some justification for the concern that they could bioaccumulate in humans (in fatty tissues and breast milk), thus building up to a concentration where toxic effects could be observed, and could be passed to nursing infants.

In fact, intake of dioxins via breast milk, usually during the first half year of life, is estimated to be relatively high. However, breast feeding occurs for only a short part of the life span (i.e., less than 4%), and its known benefits are thought to outweigh any potential risks associated with dioxins and furans in breast milk. When averaged over a lifetime, the average Canadian intake of these substances is currently below the acceptable daily intake estimate (Boddington *et al.* 1990).

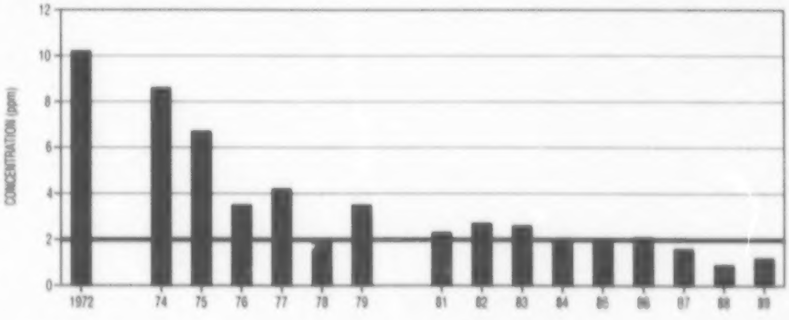
PCBs

When a chemical storehouse containing PCBs burst into flame in St-Basile-le-Grand, Quebec, on August 23, 1988, this class of compounds gained instant national notoriety, like other chlorinated chemicals before it, such as DDT. PCBs were once used extensively in many parts of the electrical and transmission industry as well as in flame retardants, waterproofing agents, printing inks, and adhesives — they were even spread on roads to keep down the dust. In 1980, tight restrictions limited the use of PCBs in Canada to closed electrical equipment. But PCBs continue to enter the aquatic environment through sewage, leachates from solid waste dumps, spills, and atmospheric deposition from incomplete combustion. The PCBs detected in northern water bodies (Gregor and Gummer 1989) are most likely a result of atmospheric deposition.

PCBs are particularly prone to bioaccumulation. For example, concentrations of PCBs in some fish species were estimated to range from 2 700 to 108 000 times the concentration found in the surrounding water (United States Environmental Protection Agency 1980). However, concentrations of PCBs are declining in fish from selected Canadian locations. From 1972 to 1989, the concentration of PCBs in coho salmon collected from the Credit River, Ontario, dropped from over 10 ppm to just above 1 ppm (Fig. 3.13). All coho sampled in 1988 and 1989 were below the 2.0 ppm federal guideline for unrestricted consumption. This trend was also demonstrated in declining PCB concentrations in rainbow trout. Concentrations of PCBs in rainbow trout taken from Lake Ontario at the Ganaraska River dropped from almost 4 ppm in 1976 to

FIGURE 3.13

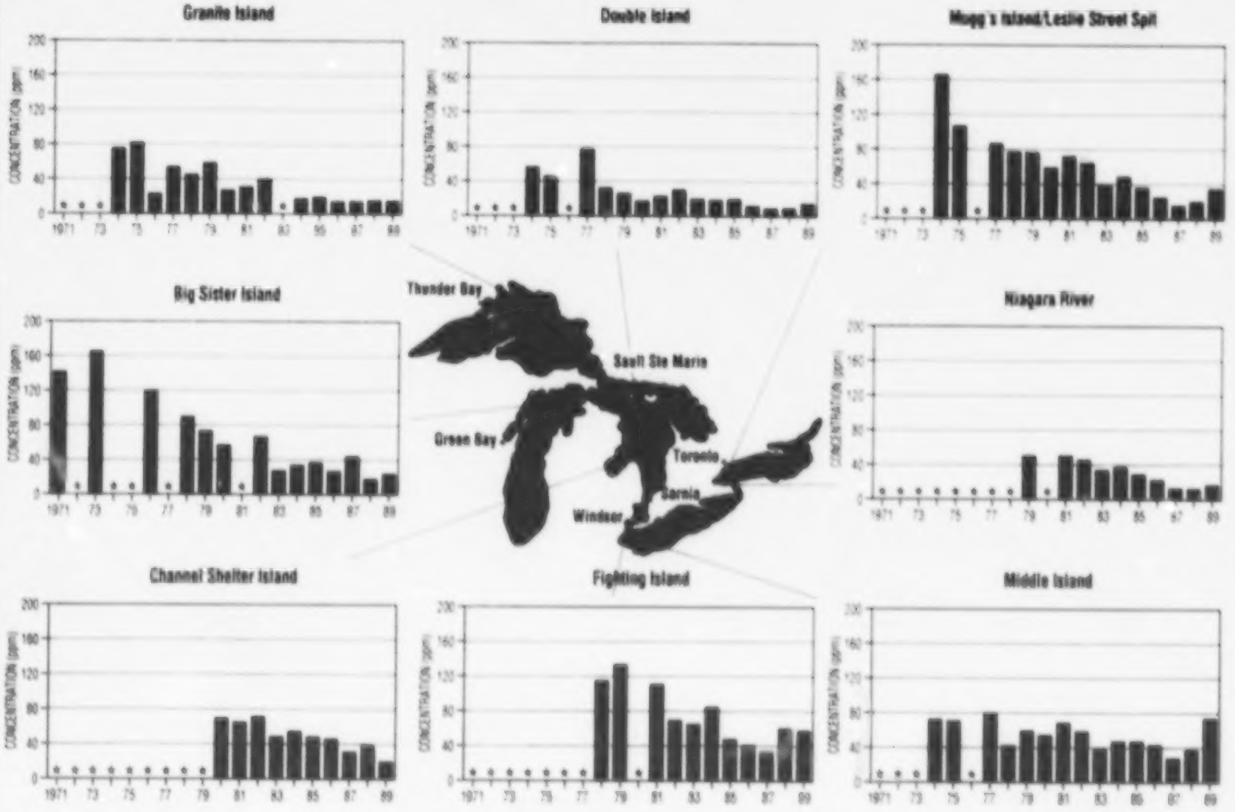
Mean concentrations of PCBs in coho salmon from the Credit River, Ontario, 1972–89



2.0 ppm = federal guideline for unrestricted consumption.
Source: Ontario Ministry of the Environment and Ministry of Natural Resources (1991).

FIGURE 3.14

Concentrations of PCBs in Herring Gull eggs in the Great Lakes



*Indicates no data.

Source: Bishop and Weseloh (1990).

just over 1 ppm in 1988. However, this still exceeds the federal objective of 0.1 ppm for PCBs in Great Lakes trout (International Joint Commission 1989). PCBs in Herring Gull eggs throughout the Great Lakes have also declined sharply (Fig. 3.14).

In response to concern in Canada, PCBs are no longer used widely in this country, and safe incineration technologies are being applied to the destruction of those in storage. PCBs, however, remain a global problem. Tanabe (1988) estimated that only 4% of the PCBs produced worldwide have been destroyed, a third have been lost to the environment, and the rest are still in use or in landfills.

Pesticides

"Pesticide" is a generic term used to describe a family of substances including herbicides, insecticides, and fungicides. About 500 types of such compounds are registered for use in more than 5 000 commercial formulations.

Pesticides are used extensively in Canada in agriculture and forestry, and in urban areas as weed-killers. Herbicides are used much more than insecticides. In 1986, 24 687 t of herbicides were sold compared to 2 857 t of insecticides. Most of the pesticides that are used today degrade relatively rapidly in the environment. However, the earlier generation of pesticides did not degrade rapidly, and some of these persistent pesticides, like DDT, have remained in the water column and sediments for years after their application. Furthermore, when contaminated sediments are disturbed, pesticides there can become suspended in the water column, making them available again to the food chain.

Aldicarb, a pesticide used on potato crops, is an example of a long-lived pesticide. An Environment Canada study detected aldicarb residues in Prince Edward Island sandstone aquifers and some wells more than five years after the last application (Priddle and Jackson 1989).

Some pesticides are linked to cancer, birth defects, liver and kidney damage, and testicular atrophy in humans. Much of the surface water tested in Canada contains small concentrations of pesticides, but they rarely exceed the Canadian guidelines for drinking water (Health and Welfare Canada 1989). As well, researchers estimate that only 20% of the pesticides that Canadians ingest on an average daily basis come from drinking water, with the remaining 80% coming from food, soil, and air (Health and Welfare Canada 1988).

Heavy metals

One tablespoon of mercury in a body of water covering a football field to a depth of 4.6 m is enough to make fish in that water unsafe to eat (Howard 1980). Likewise, lead in sufficient concentration may harm aquatic species and pose risks to human health. Although these and other heavy metals, such as copper and zinc, may be present in low amounts from naturally occurring sources, excessive concentrations are usually the result of industrial and mining activity, urban stormwater runoff, and the leaching of soils and rock by acidic deposition.

Mercury contamination of the aquatic ecosystem can occur either directly through discharges to the system (see Box 3.4) or indirectly by flooding mercury-containing soils and by air emissions from metal smelters. Approximately 80% of the mercury that enters the global ecosystem comes from natural sources. Even so, the anthropogenic sources are more ecologically significant, as the following example illustrates.

The extensive flooding of terrain at Southern Indian Lake as part of the Churchill–Nelson River Hydroelectric Development Project in northern Manitoba has resulted in elevated mercury levels in fish (Fig. 3.15). The findings have led to the realization that mercury contamination resulting from water development projects is potentially a widespread problem in Canada.

Mercury attacks the central nervous system, causing loss of sensation, tunnel vision, lack of coordination, and impairment of speech, hearing, and gait. Exposure to methylmercury

BOX 3.4

Pijibowin: the poisoning of the Wabigoon–English River system

Pijibowin — the Ojibwa word for poison. In 1970 it took on a terrible relevancy for the residents of Grassy Narrows and White Dog in northwestern Ontario when scientists discovered that the river that ran through the two Ojibwa communities, and had been their economic lifeblood, was polluted with mercury — *pijibowin*.

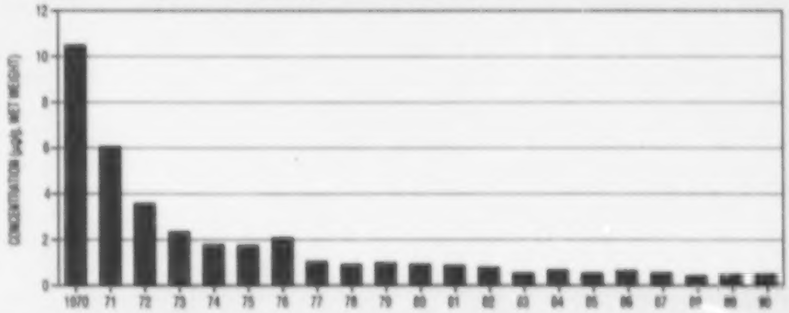
From 1963 to 1970, a pulp and paper plant in Dryden that produced chlorine from a mercury cell had discharged approximately 9–11 t of mercury into the Wabigoon–English River system (Canada–Ontario Steering Committee 1983). Fish in the Wabigoon–English River system had accumulated concentrations of mercury up to 30 times that considered "safe" (Health and Welfare Canada 1973). As a result, local Ojibwa people of the White Dog and Grassy Narrows communities, many of whom were fishing guides and heavy fish-eaters, themselves had accumulated unacceptably high levels of mercury in their blood (Canada–Ontario Steering Committee 1983).

It is impossible to separate the direct debilitating medical effects of mercury poisoning on the people of White Dog and Grassy Narrows — their degree is still a matter of scientific debate — from the devastating impacts of mercury on their economic, social, and psychological well-being. Pollution of the Wabigoon–English River system meant lost income from guiding, abrupt separation from lifestyles based on fish consumption, and a loss of faith in nature and its ability to provide.

The gradual recovery of the Wabigoon–English River system is illustrated in Figure 3.B4, which charts the decline in mercury concentrations found in the tail muscle of crayfish taken from Cray Lake, Ontario. However, cases of high mercury levels (more than 6 ppm) keep turning up in the population — most recently in a 3-year-old girl whose grandmother fed her fish frequently. Twenty years after the pulp and paper mill stopped discharging mercury into the river, provincial and federal ministries continue to advise people to restrict their intake of fish from lakes and rivers in the region (Fisher 1990).

FIGURE 3.B4

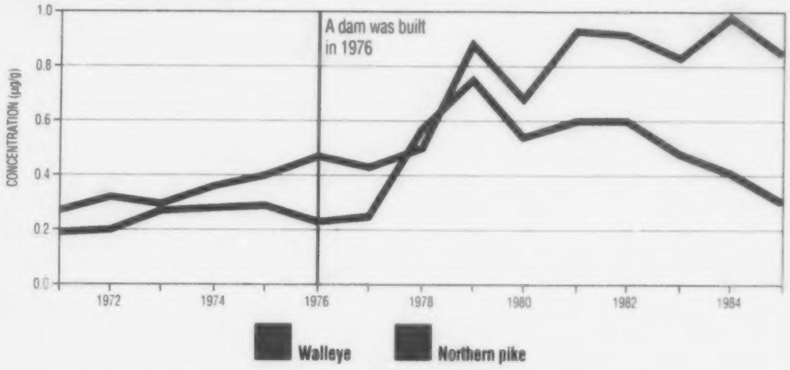
Concentrations of mercury in crayfish from Cray Lake on the Wabigoon–English River system, Ontario, 1970–90



Note: Point source at Dryden reduced by approximately 95% in 1970 and reduced to virtually zero in 1975.
Source: G.P. MacRae, Freshwater Institute, personal communication.

FIGURE 3.15

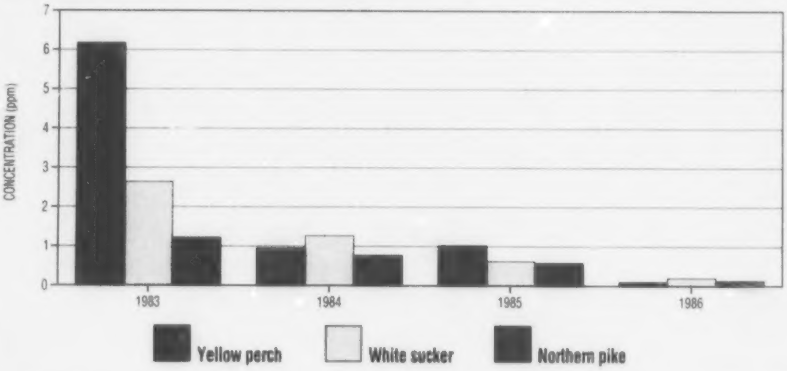
Mercury levels in commercial fish samples, Southern Indian Lake, Manitoba, 1971–85



Source: Environment Canada and Manitoba Environment and Workplace Safety and Health (1987).

FIGURE 3.16

Mean concentrations of lead in three species of fish, St. Lawrence River at Blue Church Bay, 1983–86



Source: Ontario Ministry of the Environment and Ministry of Natural Resources (1988).

during the fetal stage may lead to delayed motor and intellectual development later in life (Environment Canada and Manitoba Environment and Workplace Safety and Health 1987).

Lead, another heavy metal of concern, can cause serious damage to the nervous, circulatory, urinary, gastrointestinal, and reproductive systems (Anderson and Harmon 1985). Currently Canadians receive less than 4% of the daily total uptake of lead from drinking water. The rest is from food and air. The elimination of point sources of lead contamination can have immediate effects. For example, the source of lead in fish in the Blue Church area of the St. Lawrence was a factory manufacturing tetraethyl lead as a gasoline additive (Fig. 3.16). Efforts to reduce sporadic losses in 1983–84 were not adequate. When production at this factory ceased in 1985, lead levels in three species of fish declined to the natural background levels of lead found generally in Ontario fish by 1986 (Ontario Ministry of the Environment and Ministry of Natural Resources 1991).

DRINKING WATER: THE BEST OF GIFTS

Drinking water has been called "the best of gifts." The quality of water used for drinking — the most fundamental human use of water — has become a major concern for many Canadians in the 1990s, as evidence of general environmental degradation grows.

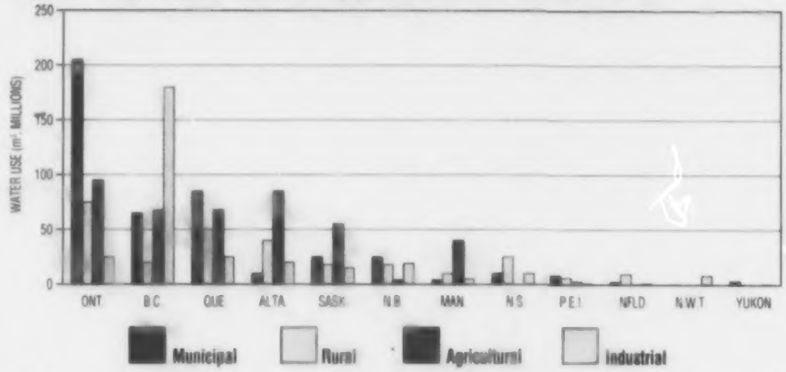
When discussing drinking water, it is important to differentiate between untreated or raw water and treated water, which, in most cases, is what comes out of the tap. In Canada, much of the environmental concern is directed at the quality of the raw sources of drinking water. Drinking water is drawn from two types of sources: groundwater (from wells and springs) and surface water (from lakes, rivers, ponds, creeks).

Though three-quarters of Canadians drink surface water, there may be as many as 2 million wells tapping into subsurface water supplies. Many Canadians rely on groundwater, rather than surface water, for their domestic and drinking water needs. Groundwater aquifers supply water at constant temperature and quality, which often makes them a superior source of supply. Over 6 million Canadians, mostly in rural areas, are tapped into these underground rivers (Fig. 3.17). Some urban areas also use mainly groundwater for municipal supply, including the Kitchener–Waterloo region in Ontario and Fredericton in New Brunswick. In fact, the proportion of Canadians drinking groundwater has more than doubled, from 10 to 26%, since 1960 (Science Council of Canada 1988). All of Prince Edward Island, parts of the prairies, many rural and some urban municipalities are partially or completely dependent on groundwater. Furthermore, most bottled water comes from natural springs.

Although some protection is provided by the layers of soil and rock, groundwater can be contaminated by surface activities. Currently groundwater in

FIGURE 3.17

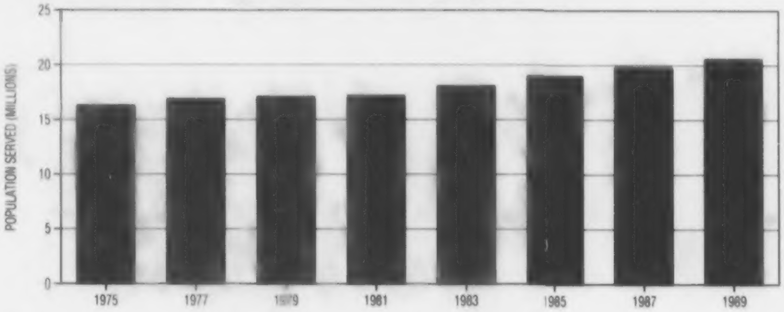
Estimated groundwater use by province and sector, 1981



Source: Hess (1986); Environment Canada (1990*b*).

FIGURE 3.18

Population served by treated water supply, 1975–89



Source: Environment Canada (1990*d*).

parts of Canada, including areas of Prince Edward Island, southern British Columbia, and southern Ontario, is being contaminated by agricultural pesticides. Furthermore, some underground storage tanks for petroleum products and hazardous wastes are deteriorating and leaking their contents into aquifers, leaving them unfit for human use. Since 1979, 500 wells in New Brunswick have been contaminated by petroleum tanks (Science Council of Canada 1988). Once contaminated, groundwater is much more difficult to clean up than surface water, and the time of recovery is much longer.

Whether drinking water has its source in surface water or groundwater, rather than rely on the natural raw water quality, most Canadian municipalities subject it to some form of treatment — by chlorination, ozonation, or ultraviolet radiation. The proportion of Canadians served by treated water supply steadily rose in the 1980s (Fig. 3.18).

Deriving Canadian drinking water guidelines

A good glass of water should be free from disease-causing microorganisms, harmful chemical substances, and radioactive matter. Guidelines for Canadian Drinking Water Quality, set by Health and Welfare Canada (1989), pertain to four broad categories: microbiological (bacteria, viruses, and protozoans), radiological (radioactive isotopes), physical (taste, odour, temperature, turbidity, and colour), and chemical.

Scientific data, collected in the field and in laboratory experiments, form the basis of the guidelines. With respect to chemical contamination, toxicological studies of the effects of chemicals on mammalian species and, occasionally, epidemiological studies on the incidence of certain health effects in groups of people accidentally exposed to a chemical are used to determine the effects of exposure to chemicals. Health and Welfare Canada uses different approaches for the derivation of drinking water guidelines depending on whether the compound is thought to be potentially carcinogenic or whether the compound is considered to be toxic but not carcinogenic.

For chemicals that are not carcinogenic, the guideline for maximum acceptable concentration is derived from the lowest no-observed-adverse-effect level (NOAEL), that is, the highest dose in a toxicity study that does not result in an adverse effect in the organism; or the lowest-observed-adverse-effect level (LOAEL). An uncertainty factor between 10 and 5 000 may be incorporated, depending on whether animal or human data were used, whether studies have been conducted on high-risk populations (i.e., pregnant or very young individuals), and the quality and number of these studies (Health and Welfare Canada 1988).

For carcinogenic substances and ionizing radiation, there is evidence that there is no level of exposure at which a hazard does not exist. Therefore, in setting guideline levels for these substances, researchers assume that any level of exposure carries some risk. Guidelines are set at levels at which the risk is thought to be sufficiently low or negligible, i.e., one person in a million developing cancer (Health and Welfare Canada 1988).

In recent years, there is a growing recognition that we need to control exposure to chemicals from a variety of sources, not only drinking water. This is taken into account when calculating the total amount of a toxic chemical or ADI (acceptable daily intake) that can be consumed through drinking water before it is dangerous to humans. Unless there is evidence that very little exposure comes from other sources, a maximum of 20% of the daily acceptable intake is allowed to come from drinking water. This approach is designed to ensure that human exposure to a contaminant from all possible pathways (air, food, water, soil) does not exceed an acceptable intake value (Health and Welfare Canada 1988).

Regardless of the approach used to arrive at the guideline, the adopted limit normally balances health benefits against such socioeconomic factors as the cost and feasibility of attaining a minimum acceptable concentration. Further, it should be recognized that socioeconomic factors may be given more weight when it comes to deciding legally binding standards than in developing ideal guidelines.

The federal government has a leadership and advisory role with regards to surface and drinking water quality. Provincial governments have the primary responsibility to legislate standards and regulations. Quebec and Alberta are the only provinces that have legislated drinking water quality standards, based on the Canadian guidelines. Legislation is pending in Ontario. Although other provinces also use the Canadian guidelines as a basis to control the quality of municipal drinking water supplies, they have not as yet implemented them as regulations. Most municipalities, which are ultimately responsible for delivery of drinking water, regularly test for only coliforms and residual chlorine. With the exception of trihalomethanes (toxic by-products formed in conventional chlorine treatment), chemical constituents are checked much less frequently — once per year in some provinces and sporadically in others. The degree to which chemicals in drinking water are monitored varies considerably from municipality to municipality.

Drinking water quality concerns

A 1990 survey revealed that 20% of Toronto residents used bottled water regularly instead of tap water. This reflects a growing perception among the public that drinking water is increasingly contaminated with pollutants, and therefore unsafe.

There are no long-term comprehensive, national studies available either to confirm or to refute the perception that tap water is no longer safe. However, a number of regional studies suggest, based on Health and Welfare Canada's (1989) guidelines, that tap water is indeed safe. For example, a recent extensive survey in Atlantic Canada carried out over a four-year period failed to detect the majority of the 150 chemicals for which analyses were done (Environment Canada 1990*c*). Where organic chemicals were detected, concentrations were well below the maximum acceptable concentrations.

A great deal of concern has been expressed over drinking water in the lower Great Lakes, because of pollution from petrochemical industries upstream and seepage from hazardous waste dumps along the U.S. side of the Niagara River. A study of Toronto drinking water carried out in 1990 by the Toronto Board of Health (Kendall 1990) detected 42 substances, though the levels were generally extremely low, in the parts per trillion range, and none was close to the guidelines. As well, in a study by the Canadian Public Health Association (1986), 31 sites around the Great Lakes were sampled and tested for 161 substances. Established standards were rarely exceeded in treated tap water.

For most of the chemicals detected in highly sophisticated surveys, concentrations recorded have been so low — hundreds or even thousands of times below health-based guidelines — that their presence in drinking water is not believed to present a significant risk to health (although human exposure through the food chain is a different matter).

In addition to the long-term, low exposure effects of individual contaminants, people have expressed concern over the possibility that synergistic effects may occur when there are mixtures of minute amounts of a large number of contaminants. Additive effects are more common, however, than either synergistic or antagonistic effects.

In the past, concerns over drinking water quality generally have centred on the source water from which drinking water is taken. Recently, concerns over the treatment of drinking water have surfaced. Conventional treatment with chlorine has been questioned because of the formation of toxic by-products, the most important of which are trihalomethanes or THMs. The guideline for THMs is at present under review. In light of the probable carcinogenicity of several of the trihalomethanes and the consequent need to reduce their concentration to as low a value as practicable, disinfection practices have been altered in many systems. THM formation can be effectively reduced in some instances by relatively simple changes in the treatment process, including reducing the quantity of chlorine, changing the point of application of chlorine, improving pH control to minimize THM formation, and using an alternative disinfectant, either alone or in conjunction with chlorine.

Future work will be required on guidelines for other direct additives to drinking water supplies. Reports of an association between aluminum and the degenerative brain disease known as Alzheimer's have called into question the use of aluminum sulphate, which is frequently added to drinking water as a settling agent to remove particulate contaminants before filtration. Health and Welfare Canada is continuing to monitor the toxicological data, which are inconclusive at this time.

ENSURING PLENTIFUL, CLEAN WATER: AN INTEGRATED APPROACH

The very nature of aquatic ecosystems — fluid, therefore, interconnected and ever-changing — necessitates an integrated approach to solving problems of water quality and quantity. Success in dealing with these problems will require that the left hand know what the right hand is doing. Monitoring, research, and management must be coordinated within geographical regions. Sectoral data and research will continue to provide a base of information, but data should be integrated to make it more meaningful. Emphasis must shift from a sectoral approach (i.e., water quality, quantity, and use, fisheries, forestry, etc.) to a more holistic approach where all parts of the ecosystem, including humans, are considered. For example, addressing non-point sources of pollution will require management of chemicals from their production through their distribution and disposal — in other words, from cradle to grave. Above all, greater emphasis must be placed on monitoring the health of the entire ecosystem and not simply the amount of effluent coming out the end of a pipe.

There are many organizations and people that must be involved if water and the aquatic environment are to be soundly managed. The roles of the federal, provincial, territorial, and municipal governments; the private sector; nongovernmental organizations; and individuals must be coordinated. Governments are beginning to work with industry and the public to develop concrete plans to address both regional and national problems. The St. Lawrence Action Plan, funded by Quebec and the federal government, and Ontario's Municipal/Industrial Strategy for Abatement are good examples of the kind of cooperation among various levels of government, the private sector, environmental nongovernmental organizations (ENGOs), and the general public that will be required to successfully address the problems facing aquatic ecosystems.

In 1988, the Science Council of Canada urged that water be moved to the top of the political agenda, because its quality and availability are key to both economic and environmental health. In its Green Plan, released in December 1990, the federal government announced its commitment to addressing some of the problems currently threatening Canada's aquatic ecosystems (Government of Canada 1990). Plans are being developed to clean up past messes in the Fraser River basin and Atlantic harbours and coasts. The government is proposing a joint initiative with the provinces of Manitoba and Saskatchewan to study the environmental stress on the Red and Assiniboine river basins. The federal and provincial governments, industry, and other sectors continue to work to remediate the pollution problems of the Great Lakes and St. Lawrence.

Improved water science, on a national level, is required to anticipate and prevent further degradation of aquatic ecosystems (Science Council of Canada 1988). The Green Plan will establish a Great Lakes Pollution Prevention Centre by 1992 and increase federal expenditures in water-related science and technology, in cooperation with the provinces and industry. Also, to prevent further degradation of aquatic ecosystems, a national regulatory action plan has been announced. It includes control of emissions of dioxins and furans from pulp and paper mills, as well as new limits on other pulp and paper industry effluents, to be issued in 1992 for full implementation by 1994.

Key to any success in sustaining the health of aquatic ecosystems is public involvement. To increase the environmental awareness and involvement of Canadians, the federal government will provide additional funding to Canada's ENGOs and will initiate environmental education programs in several areas including water.

Global issues such as climatic change represent additional complications for water management. Like many of the environmental problems of today, the problem of climatic change will require participation of more than one country. In the future, bilateral and multilateral agreements and protocols must become increasingly important if global environmental issues are to be confronted and abated.

CONCLUSION

Because all life essentially depends upon water, the health of aquatic ecosystems is a good indicator of the state and sustainability of the environment. Canada still has a number of lakes, rivers, and groundwater aquifers that could be considered pristine. But we also have aquatic ecosystems collapsing from acidification or human-induced eutrophication; rivers used as sinks for municipal and industrial effluent and contaminated with agricultural and urban runoff; and aquifers contaminated by pesticides, gasoline, and other organic chemicals.

Progress has been made towards slowing, and in some cases reversing, the degradation of Canada's aquatic ecosystems. With the virtual elimination of the point source of mercury in Dryden, Ontario, the Wabigoon–English River system has shown a gradual recovery over the last two decades (Fig. 3.B4). There has been mixed success in reducing some contaminants. Concentrations of 2,3,7,8-TCDD have decreased in Herring Gull eggs in the Great Lakes since the mid-1970s, when production of the pesticide 2,4,5-T ceased. At the same time, dioxin and furan contamination has caused the closure of some inland and coastal fisheries. The positive response of the Great Lakes to controls placed on phosphorus in the 1970s showed that regulations can have a dramatic effect on reducing pollution. Conversely, continuing eutrophication problems in many prairie rivers, acidification of eastern Canadian lakes, increasing nitrogen concentrations in the Great Lakes, and the presence of pesticides and other contaminants originating on land underscore the need to address non-point sources of pollution to aquatic ecosystems.

The *Drinking Water Safety Act*, promised by the federal government in its Green Plan, provides the authority for legally enforceable standards for drinking water in areas under federal jurisdiction. To safeguard drinking water in the future, Canadians should perhaps shift the focus of concern from the quality of what comes out of the country's taps to what is going into its sources of raw drinking water — substances that require increasingly sophisticated techniques to remove and whose long-term effects are unknown.

In the face of emerging issues, ensuring clean water in sufficient supply for future generations of Canadians will require the use of new management tools and the involvement of governments, private sector, the public, and ENGOs, all committed to a healthy aquatic environment. Failure to protect water resources from contamination and depletion would be an unmitigated disaster, for fresh water is truly the lifeblood of the environment.

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4

COURTESY OF INDUSTRY SCIENCE AND TECHNOLOGY CANADA, OTTAWA

HIGHLIGHTS

There are many inshore areas and estuaries on Canada's three coasts that exhibit evidence of environmental degradation, in some cases severe, with significant risk to living resources, habitats, and occasionally even public health.

■

Myriad contaminants — heavy metals, hydrocarbons, and chlorinated organics — have been detected in nearshore fauna and their environments. Concentrations of chlorinated organic compounds in the eggs of seabirds from the St. Lawrence estuary indicate the region continues to be one of the most polluted marine areas in Canada, followed by the Bay of Fundy, the Strait of Georgia, and the west coast of Vancouver Island.

■

The single largest human pressure on the Canadian marine ecosystem is the removal of approximately 1.5 million tonnes of fish by national and foreign fisheries each year. Although the level of harvest for most fish stocks is generally sustainable, a few stocks have suffered short-term declines due to overfishing. This has contributed to the closure of fish plants in Atlantic Canada over the past several years. Determining the full impacts of harvest levels will require further study. The effects of harvesting on food chains and other aspects of the overall marine ecosystem are not well understood.

■

The federal government has responded to the current crisis of low groundfish numbers by introducing a five-year, $584-million Atlantic Fisheries Adjustment Program to improve fisheries science, to enhance resource conservation, and to assist industry diversification, including development of aquaculture.

■

Pressures imposed by coastal population growth are less severe than those in the southern United States and the Mediterranean basin. However, increases in population between 1971 and 1986 in centres including Vancouver (28%), Victoria (32%), St. John's (22%), and Halifax (18%) have introduced stressors into coastal areas.

■

Disposal of untreated sewage and industrial contaminants into coastal waters is limiting Canada's ability to cultivate, harvest, and market shellfish. Pathogenic organisms from municipal wastewater discharges are implicated in about half of shellfish closures nationally.

■

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> “
>
> **A great and diversified complex of current and tide, of offshore banks and oceanic littoral, of pasture and ploughland, of mountain and salmon river, of orchard and expansive tideland, has passed through the full cycle of recovery from the ice age and from its collision with civilization, and has emerged — damaged, to be sure — a monument to the vitality of nature.**
>
> ”
>
> — Franklin Russell (1970),
> *The Atlantic coast*

> “
>
> **It is not my intention to question man's right to tame this coastal wilderness and harvest its natural resources for his own use. But with hindsight now, it is clear that greed and waste, prompted by motives of immediate gain without thought or planning for future yields, produced methods of resource use from which we are reaping steep losses still today.**
>
> ”
>
> — Fred Bodsworth (1970),
> *The Pacific coast*

> “
>
> **And though the northern seas are chill and dismal and their denizens often drab, the number of fish is legion and it is they who feed the whales, the largest creatures that ever lived on earth, and the sea elephants, the seals and walruses.**
>
> ”
>
> — Fred Bruemmer (1982),
> *The Arctic*

INTRODUCTION

Three bountiful oceans — the Atlantic, Pacific, and Arctic — wash Canada's shores. At 244 000 km, the country's coastline is the longest in the world; its continental shelf, at 3.7 million square kilometres, is the second largest in the world. Given Canada's maritime preeminence, it is hardly surprising that, historically, oceans and coasts have played an important role in helping Canadians meet vital subsistence — as well as economic, social, and cultural — needs. Oceanic and coastal ecosystems also host a wide diversity of life, including marine mammals, seabirds, invertebrates, and commercially valuable fish populations.

Each of Canada's oceans has unique physical features that influence the plant and animal life it supports. The Pacific coast has a continental shelf less than 50 km wide and a rugged shoreline characterized by numerous islands and fjords. The Atlantic has a much wider continental shelf — in some places 300 km wide — that supports major fisheries in the Labrador Sea and on the Grand Banks, Scotian Shelf, and Georges Bank. Arctic waters are generally less productive biologically, but ice-free areas, called polynyas, provide polar oases for overwintering whales, seals, polar bears, and seabirds. Intense spring phytoplankton "blooms" attract several species of marine mammals, birds, and fish in great abundance.

In addition to their role in supplying a wealth of natural resources, essential to our economy and society, Canada's oceans are important as corridors for seaborne trade and commerce, as sources of energy and nonrenewable mineral resources, as recreational areas, and as unique natural wildlife areas in their own right. Industries such as shipbuilding and marine services, shipping, fishing, offshore oil and gas, transportation, tourism, and oceans-related manufacturing and services industries are key components of the Canadian economy. In 1988, oceans-related industries generated over $6 billion of Canada's national income and provided approximately 165 000 jobs (Table 4.1). In the same year, fisheries accounted for about half of that oceans-related national income and about 75% of the jobs.

The economic benefits provided by the oceans, however, cannot be considered in isolation from marine ecosystems, for they interact in diverse and complex ways. Overexploitation of marine and coastal resources can have adverse effects on ecosystems and human welfare. If resource-use practices are not sustainable, the environment and, ultimately, the economy will suffer.

Already, Canadians are witnessing the consequences of loss of marine environmental quality. Coastal development has led to habitat loss or degradation. Waste disposal practices are injuring or, in some cases, destroying marine organisms and marine habitats. Atmospheric changes may also have serious consequences for life in the seas and coastal property. The increasing pressures on marine and coastal environments, many related to human activities, are challenging our ability to protect and restore marine ecosystems and, ultimately, to ensure the benefits of our bountiful seas for future generations.

HUMAN ACTIVITIES AS AGENTS OF CHANGE

Life in the sea is influenced by many factors, including atmospheric processes, ocean currents, nutrient upwelling, and runoff from land. In addition to these natural phenomena, present-day industrial society also exerts pressures on marine ecosystems. In some cases, these pressures have dramatic impacts on human health and well-being.

Much of the waste that ends up in the oceans is discharged from land-based pollution sources (Table 4.2). Such discharges account for up to 80% of the oceans' total pollutants — sediments, nutrients, and chemical and biological contaminants. Nearshore areas can be severely affected by such discharges, particularly where water circulation is restricted. Much of it is carried to the sea by streams and rivers. In addition, airborne contaminants can travel thousands of kilometres through the atmosphere to fall with rain or dust. Ocean currents then mix, redistribute, and transform this pool of pollutants.

Human activities can inflict a litany of ills on the marine environment: bacterial/viral contamination, oxygen depletion, toxicity, bioaccumulation, habitat degradation, depletion of biota, and degradation of aesthetic values (Table 4.3). Examples of cause-and-effect relationships are numerous: fecal contamination from sewage has degraded the aesthetic and recreational value of beaches, leading to beach closures on two coasts; solids, including fibre, bark, and other mill residues, have smothered life on the seafloor; bioaccumulation of dioxins and furans in coastal areas near pulp and paper mills has closed fisheries and may be impairing wildlife; and offshore oil and gas exploration and production drilling wastes have altered life on or within patches of the seafloor. Furthermore, coastal food-processing operations continue to dump oxygen-consuming wastes into nearshore waters, threatening aquatic life; urban and agricultural runoff is injecting toxic pesticides into the marine environment; and overfishing and habitat loss are depleting some stocks of commercially valuable species.

Contaminants in the marine environment can have direct effects on the health of marine ecosystems. Innovations in chemical technology after World War II led to a proliferation of new toxic chemicals, such as the synthetic chlorinated organic compounds (e.g., DDT and PCBs). These compounds and toxic heavy metals (e.g., mercury and lead) can bioaccumulate in animal tissues, and some of them increase in concentration through the food web (biomagnification). As a result, the threat that toxic contaminants pose to the marine ecosystem and human health can be enhanced (see Chapter 21), as exemplified by the high concentrations of dioxins and furans in the eggs of Great Blue Herons in the Strait of Georgia, British Columbia, and their suspected role in causing reproductive failure in the seabird colonies.

Contamination also may have indirect effects. Sewage discharges, fertilizers in runoff, and industrial discharges of food wastes, for example, can result in increases in dissolved nutrients in coastal waters, which in turn can lead to algal blooming and subsequent oxygen depletion, which threatens most aquatic life. In addition, blooms of toxic phytoplankton species can be taken up by commercially viable shellfish, making them temporarily unfit for human consumption.

TABLE 4.1

Estimated income from, and employment in, selected oceans-related industries

Industry	**Year**	**Income ($ billions)**	**Employment[a] (000s)**
Fisheries	1988	3.2	123.0[b]
Oil and gas	1988	0.3	1.6
Marine shipping	1988	2.3	23.8
Shipbuilding and ship repair	1988	0.5	10.5
Oceans-related manufacturing and services	1986	0.3	6.2
Total		**6.6**	**165.1**

[a] Represents jobs and not necessarily person-years of employment.

[b] Data are for 1987.

Source: Department of Fisheries and Oceans (1987).

TABLE 4.2

Some marine activities and land-based sources of marine contamination that affect marine organisms on Canada's three coasts

Contaminant or activity	**Atlantic**	**Pacific**	**Arctic**
Exploration for, and exploitation of, oil and gas reserves	xx	xx	xxx
Ocean dumping	xx	x	x
Coastal developments (e.g., harbours, marinas, causeways)	xx	xx	xxx
Discharges of municipal wastewater	xxx	xxx	xx
Discharges from pulp and paper mills	xxx	xxx	–
Oil refineries	xx	xx	–
Chemical industries (e.g., chlor-alkali plants)	x	x	–
Mining wastes	xx	xx	xx
Chemical spills and leaks from shore installations	x	x	x
Urban and agricultural runoff	xxx	xxx	x
Litter (e.g., plastics, logs, nets)	xx	xx	xx
Agriculture (nutrients, siltation)	x	x	–
Pesticides in agriculture and forestry	xx	x	–
Atmospheric emissions	x	x	xx

Note: The symbols show level of concern: xxx is very high, xx is high, x is moderate, and – is low. The somewhat subjective rankings are based on proven ecological damage and on losses in resource sectors of the economy.

Source: Waldichuk (1988).

TABLE 4.3

Potential effects on the marine environment of various activities and sources of contamination

Activity or source of contamination	Bacterial/viral contamination	Oxygen depletion	Toxicity	Bioaccumulation	Habitat degradation	Depletion of biota	Degradation of aesthetic values
Exploration for, and exploitation of, oil and gas reserves		x	x	x	x	x	x
Ocean dumping	x	x	x	x	x	x	
Coastal developments	x				x	x	x
Discharges of municipal wastewater	x	x		x	x	x	x
Discharges from pulp and paper mills	x	x	x	x	x	x	x
Food and beverage processing		x			x		x
Oil refineries			x	x			x
Chlor-alkali plants			x	x			
Mining wastes			x	x	x	x	x
Chemical spills and leaks		x	x	x			x
Urban and agricultural runoff	x	x	x	x	x		
Litter					x	x	x
Agriculture	x	x	x	x	x		x
Pesticides			x	x			
Atmospheric emissions	x		x	x			

Source: Waldichuk (1988); T.R. Parsons, University of British Columbia, personal communication; D.J. Thomas, Seakem Oceanography Ltd., personal communication.

Each of Canada's three oceans shows the effects of intensified human activities in marine and coastal environments. Resource exploitation, coastal development, and contaminant inputs have effects at both species and ecosystem levels, but the understanding and assessment of these effects are often constrained by inadequate knowledge of the basic functioning and dynamics of marine ecosystems. Along each coast, there are environmental "hot spots" (see Tables 4.4–4.6) that either have suffered severe chemical and bacteriological contamination or physical degradation or are threatened by projected development. This section highlights some of the major marine environmental quality issues, drawing upon examples from territorial waters off Canada's Atlantic, Pacific, and Arctic coastlines and from the world oceans.

Fisheries

National and foreign fishing fleets remove approximately 1.5 million tonnes of fish each year from Canada's oceans (Food and Agriculture Organisation 1988; Parsons, in press). The removal of this quantity of fish constitutes the largest single human pressure on the Canadian marine ecosystem. Catch statistics, however, do not reflect the full impact of harvesting on the marine system, as they do not account for unreported catches, especially the unwanted catch of unmarketable species, which is simply dumped at sea.

The ecological effects of this level of harvest are not well understood. Further research is required on ecosystem dynamics to determine how the removal of commercial species affects other components of the marine environment. Harvesting at current levels may be altering delicate balances (such as those between populations of predator species and populations of prey) with as yet undetermined consequences.

Commercial fishing injects much-needed capital into coastal economies: $2 billion on the Atlantic coast and $960 million on the Pacific coast. Although the intention is to manage the fishery on a sustainable basis, there is undue pressure on certain stocks due to overfishing and pollution. Overfishing, by both domestic and foreign fisheries, has resulted in severe depletion of several stocks of commercial species in both the Atlantic and the Pacific (see Chapter 8).

Fish populations

One of the most important fishing areas in Atlantic Canada, the Grand Banks, extends beyond Canada's 200-mile jurisdiction. There, especially on the Nose and Tail of the banks and on the Flemish Cap, fishing by nonmembers of the North Atlantic Fisheries Organization (e.g., Korea and the United States) and by certain members exceeding their quotas has resulted in overfishing. Overcapacity in the domestic fleet, especially the dragger fleet, also has led to overfishing of several Atlantic groundfish (bottom-dwelling) stocks, such as cod and haddock, and, consequently, to fish plant closures in 1989 and 1990. The Pacific salmon fleet is also characterized by too many fishing vessels chasing too few fish (Government of Canada 1990*b*).

TABLE 4.4

Places of environmental concern on the Atlantic coast

Location	Concerns
St. Lawrence River and estuary	• multiple industrial inputs • contamination in species exploited by the fishery • chlorinated organic compounds in whales
Chaleur Bay[a]	• multiple industrial inputs • ocean disposal/dumping
Restigouche estuary, Chaleur Bay	• industrial contaminants • ocean dumping • degradation of fish (especially salmon) habitat
Miramichi River estuary	• pulp and paper contaminants • dredging • metals
Northumberland Strait	• pesticides • nutrient/sediment loadings • natural toxins • effect of proposed "fixed link" between P.E.I. and the mainland
N.B., N.S., P.E.I. coasts	• bacteria/contaminants/paralytic shellfish poisoning
Bras d'Or Lake, Cape Breton	• aquaculture/other use conflicts
Shubenacadie–Stewiacke basin, N.S.	• multiple conflicting uses
Lower Bay of Fundy: St. Croix estuary, Letang estuary, Annapolis basin	• contamination of shellfish, disruption of fish migration, destruction of lobster habitat
Georges Bank	• conflict between oil and gas development and fisheries
Southeast coast of Newfoundland	• Grand Banks oil and gas • coastal shipping
Various harbours	• municipal and industrial pollution • conflicting uses

[a] Also considered as southern Gulf of St. Lawrence (Messieh and El-Sabh 1988).

Source: Wells and Rolston (1991).

Although efforts are ongoing to improve the selectivity of fishing gear, losses do occur with respect to nontarget fish species (those of the wrong age or species), marine mammals, birds, and reptiles. Further study is needed to document the by-catch and its impact on species populations. In addition, scientific study is required to better understand the impact of gear movements on benthic communities and the extent to which habitat is affected. In Atlantic Canada, the trawler fleet is believed to drag nets over 30 000 km^2, or 15% of Canada's Atlantic continental shelf, annually, which may alter benthic communities.

On the high seas of the North Pacific, the Japanese, Taiwanese, and South Koreans have been fishing for squid using drift, or gill, nets attached to floats or drift boats for over 10 years. Approximately 700 vessels from the three nations are involved, setting 3 million kilometres of drift nets annually. In addition to squid, the annual by-catch of nontarget species by the drift-net fisheries is an estimated 87 000 marine mammals and 750 000 seabirds (Beamish *et al.* 1989; International North Pacific Fisheries Commission 1990) and about 40 000 t of salmon and 15 000 t of albacore tuna (S. Mckinnell, Department of Fisheries and Oceans, personal communication). Canadian concerns with the high-seas drift-net fisheries include:

- the high by-catch of nontarget species, including marine mammals, seabirds, sea turtles, and finfish such as salmon, tuna, billfish, and shark;
- the catch and illegal retention of salmonids by vessels targeting principally for squid;
- the impact of this fishery on the squid population;
- the problem of marine debris, especially lost or discarded nets ("ghost fishing").

Data on annual known total catches of managed fish stocks are useful measures of the pressure that fisheries exert on the marine environment. They do not, however, account for unreported catches. Neither do they reflect impacts that fishery activities have on food chains and the marine ecosystem, although shifts in species composition suggest that there have been such effects. It is possible, for example, that so-called "trash" species, such as dogfish on the Atlantic coast, have proliferated in the absence of competition from heavily fished commercial species. These species, however, normally show some period of increase and subsequent decrease of abundance.

Populations of pelagic (open sea) species such as herring have been undergoing significant fluctuations. Why fish populations boom, then crash, is not known with any degree of certainty. In some cases, natural or environmental factors such as food supply or climate change may be responsible; in other instances, human activity, particularly overfishing, has clearly been responsible. The virtual demise of the Georges Bank stock of herring, now slowly rebuilding, was due to a combination of overfishing and a period of adverse environmental conditions.

At present, knowledge of the natural or biological factors, including fish behaviour, that affect biological capacity and contribute to population fluctuations of fish stocks is incomplete. Moreover, more information on commercial catches in Canadian waters off the Atlantic and Pacific coasts is essential for a complete picture of commercial fisheries in coastal areas of Canada (see Chapter 8) (Indicators Task Force 1991).

The federal government has responded to the current crisis of low groundfish numbers by introducing a five-year,

$584-million Atlantic Fisheries Adjustment Program to improve Canada's capability in fisheries science, to enhance conservation of fish stocks, and to help industry to diversify into, for example, aquaculture — a growing industry on the east and west coasts.

Contamination of shellfish areas

Many productive areas on the Atlantic and Pacific coasts have been contaminated by municipal or industrial effluents. In the Maritime provinces, for example, commercial fisheries have been closed in Belledune, as a result of heavy metals, and in Sydney Harbour, because of contamination by feces and polycyclic aromatic hydrocarbons (PAHs) in lobsters. In 1989, over 39% of the area classified as suitable for direct harvesting of shellfish on Canada's Atlantic coast, excluding Quebec, was closed — an increase of 70% since 1975 (Fig. 4.1). Fecal contamination has also affected bivalve aquaculture production. In Newfoundland, as of January 1989, 30% of proposed aquaculture sites were rejected because of high fecal coliform levels. The 44 sites represent 127 km of coastline (U. Williams, Department of Fisheries and Oceans, personal communication).

Approximately 70 000 ha along 730 km of Pacific coastline, most of it productive for growing shellfish, were closed to shellfish harvesting in 1988 as a result of bacterial contamination, mainly from sewage. A large part of the closed area is in the Fraser River estuary and adjacent Boundary Bay. Until 1987, the trend in shellfish closures was stable or slowly decreasing. Between 1986 and 1988, a 24% increase was reported (Fig. 4.1). Most of this sudden statistical jump, however, was due to expanded surveillance and reporting as well as the administrative decision to close areas around wharves and marinas, rather than to increased pollution levels, but it implies a previous underestimate of affected areas (Indicators Task Force 1991).

TABLE 4.5

Places of environmental concern on the Pacific coast

Location	Concerns
Lower Fraser River and estuary	• discharges of municipal wastewater • PAHs and dioxins • pulp and paper effluents • contaminated fish
False Creek, Vancouver Harbour	• contaminated sediment • PCBs and PAHs
Vancouver Harbour	• metals • organotins and PCBs • contaminated fish
Victoria Harbour	• disposal of municipal sewage • contaminated sediments
Howe Sound	• contaminated fish • pulp and paper effluents • contaminated emissions and effluents from industry • ocean dumping • mercury
Kitimat Arm	• effluents from aluminum smelter • contaminated fish • contaminated sediments
Rupert Inlet and Alice Arm	• disposal of mine tailings • metal contamination of sediments and biota
Neroutsos and Alberni inlets	• disposal of mine tailings • sediment contamination • pulp and paper contamination
Prince Rupert	• dioxins and crab fishery • metal contamination of foreshore • disposal of municipal sewage

Source: Wells and Rolston (1991).

TABLE 4.6

Places of environmental concern on the Arctic coast

Location	Concerns
Tuktoyaktuk Harbour	• contaminated sediment • hydrocarbon spills • disposal of municipal sewage
Western Arctic	• industrial noise and cetaceans • disposal of drilling mud • long-range transport of airborne pollutants • disposal of municipal sewage • dredging/habitat disruption/turbidity • oil spills
Lancaster Sound	• habitat protection from ships • impact of ice-breaking vessels • industrial noise and cetaceans • mine tailings/habitat disruption • disposal of municipal sewage • long-range transport of airborne pollutants
Hudson Bay	• hydroelectric development/change in freshwater discharge cycle, mercury release • toxic contaminants in wildlife

Source: Wells and Rolston (1991).

Offshore oil and gas development

Offshore oil and gas development can have direct or indirect impacts on marine ecosystems. Exploration and production activities may result in temporary disruption or alteration of habitats, whereas operational or accidental releases of toxic substances may contaminate sediments and water and degrade habitat for long periods. Limited capabilities to respond to offshore emergencies, such as iceberg collisions with production rigs, and to contain marine spills are key issues related to offshore oil development.

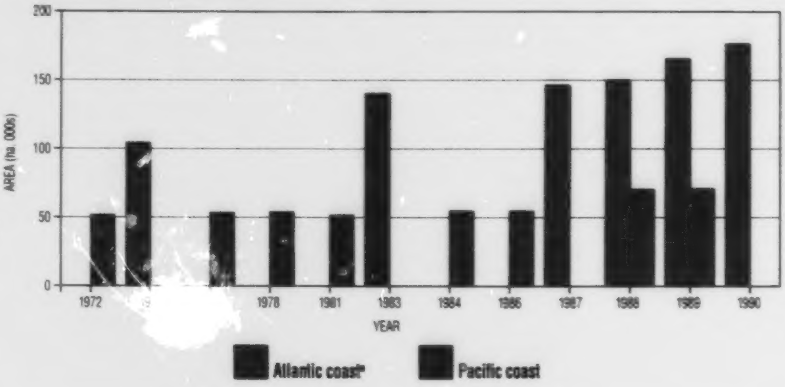
In the drilling of a well, large amounts (typically 200–500 m^3) of drilling muds and drill cuttings are discharged directly into the ocean. Mud additives used in the drilling process are of particular concern because they can contain a variety of contaminants, including heavy metals, hydrocarbons, and biocides. In general, the effects of discharges from drilling are confined to areas within 500 m of the site (Thomas *et al.* 1984).

Spills and blowouts of oil and gas in offshore waters are a major threat to all three of Canada's coasts and have occurred in the past. In 1973, offshore drilling for petroleum hydrocarbons began in the Canadian Arctic — an area extremely sensitive to pollution because of low temperatures and low species diversity. In 1972, on the Pacific coast, the Government of British Columbia imposed a moratorium on offshore exploration (which has not been lifted), whereas the federal and Nova Scotia governments have banned exploration activity in the Georges Bank area until the year 2000 in response to lobbying by the fishing industry (Wells and Rolston 1991). Additional research and development are needed to quantify the risk, fate, and environmental effects of potential oil spills from offshore production activities and facilities.

By 1989, 130 wells had been drilled off the Arctic coast and 273 wells off the Atlantic coast (Packman and Shearer 1988; Canadian Oil and Gas Lands Administration, data on file). Activity in the oil and gas industry has declined since the mid-1980s because of low world oil prices. However, the Hibernia oil project, worth $8.5 billion, smaller offshore oil development projects on the Scotian Shelf (the Cohasset and Panuke fields), and gas reserves on the Venture Field near Sable Island represent opportunities for economic expansion on the east coast. These developments, expected to come into production in the next few years, must also be viewed as posing potentially significant threats to local marine life — for example, fish populations on Newfoundland's Grand Banks and the Sable Island breeding ground for grey and harbour seals (Eaton *et al.* 1986; Wells and Rolston 1991).

FIGURE 4.1

Area closed to shellfish harvesting because of fecal coliform contamination, 1972–90



[a] Data are not available for Quebec.

Source: Indicators Task Force (1991).

Marine shipping

Ships leave contaminants in their wake. An international group of experts on the scientific aspects of marine pollution (GESAMP 1990) reported, for example, that marine transportation — including tanker operations, other shipping activities, and accidental spills from ships — accounts for an estimated 46% of the annual total input of oil to the sea.

There are many small-scale spills associated with marine shipping (G. Cloutier, Environment Canada, personal communication). Much of this pollution occurs during normal operations at sea, whether intentionally or unintentionally. Marine shipping activities can affect the marine environment through the exchange of ballast water[1] and the release of bilge water, black water (sewage), chemicals, garbage, and miscellaneous pollutants. Additionally, there is an emerging concern for the potential risk to the Canadian marine environment arising from the presence of exotic organisms that may be contained in ballast water taken on in a foreign port and discharged into a Canadian port. The introduction of zebra mussels into the Great Lakes ecosystem is generally attributed to their presence in the ballast water discharged from a European vessel in about 1985. Unintentional pollutant releases may include hydraulic oils from deck machinery, toxic releases from hull coatings, hose leakages, and cargo losses (D.B. Ross, Canadian Coast Guard, personal communication).

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[1] Ships that have unloaded their cargo but do not immediately reload may take on water as ballast. The ballast water, discharged when they next reload, may be contaminated with the previous cargo (e.g., oil, wine, ore).

TABLE 4.7

Regulations that restrict the discharge of polluting substances from ships in Canadian marine waters

Polluting substances	Oil Pollution Prevention Regulations	Garbage Pollution Prevention Regulations	Pollutant Substances Regulations	Air Pollution Regulations	Arctic Shipping Pollution Prevention Regulations
Oil	Not allowed anywhere in Canadian waters (internal waters, territorial seas, and fishing zones)	n/a[a]	n/a	n/a	Not allowed except to save life or the ship or due to stranding, collision, foundering, or normal leakages
Garbage	n/a	Not allowed anywhere in Canadian waters (internal waters, territorial seas, and fishing zones)	n/a	n/a	Not allowed by the Safety Branch of the Canadian Coast Guard
Sewage	n/a	n/a	n/a	n/a	Specifically allowed
Chemicals	n/a	n/a	Not allowed for specified chemicals anywhere in Canadian waters (internal waters, territorial seas, and fishing zones)	n/a	Not allowed by the Safety Branch of the Canadian Coast Guard
Grey water[b]	n/a	n/a	n/a	n/a	n/a
Stack emissions	n/a	n/a	n/a	Specifies limits of smoke density in all Canadian waters within 1 mile of the coast	n/a

[a] n/a = not applicable.

[b] Grey water is wastewater from domestic functions such as washing, often reused as a feed for sewage or "black" water.

Source: T. Anderson, Melville Shipping Ltd., Ottawa, personal communication.

Shipping accidents contribute to this ongoing problem at an international level, sometimes in overwhelming doses, as in the case of the *Exxon Valdez*. It appears, however, that many accidents can be avoided. The Public Review Panel on Tanker Safety and Marine Spills Response Capability (1990) for Canada stated that the overwhelming majority of tanker accidents are caused by human error; despite this, competitive pressures have reduced crews to dangerously low levels and made quick port turnarounds a growing priority. The report also indicated that almost all operational releases — spills during loading and offloading, tank washings, and discharges of wastewater — can be avoided.

Legislation controlling pollution from the marine shipping industry has significantly improved in the past two decades. Ships operating within Canadian waters and fishing zones are subject to strict pollution-related legislation, including the *Canada Shipping Act* and the *Arctic Waters Pollution Prevention Act*. Several sets of regulations exist for the purpose of pollution prevention (Table 4.7). Proposed Canadian Pollution Prevention Regulations will also eventually deal with all pollutants, but the current draft is concerned principally with oil pollution (D.B. Ross, Canadian Coast Guard, personal communication).

Despite the fact that the Public Review Panel on Tanker Safety and Marine Spills Response Capability (1990) indicated that the capability to respond effectively to a spill of any significant magnitude does not exist anywhere in Canada, progress has been made by industry to enhance spill response capabilities. For example, the Canadian Petroleum Products Institute (1991) has committed approximately $40 million (1991–93) to improve its marine oil spill response capability. It has strengthened its two existing Marine Spill Response Centres, one in the Vancouver area on the west coast and one in the Great Lakes area. Two new centres have also been established, one in Lévis, Quebec, to cover the Montreal–Quebec City corridor of the St. Lawrence River, and one in Halifax. In addition, Green Plan funding of $100 million to enhance Canada's capability to respond to marine spills was announced on June 26, 1991 (Government of Canada 1990*a*).

In the interests of preventing environmental damage from marine spills, research aimed at establishing coastal response centres, understanding and reducing impacts of spills, and increasing efficiency of cleanup operations has been going on in Canada for over 15 years (Indicators Task Force 1991). At present, the Canadian Coast Guard has 52 equipment depots including booms, skimmers, and boats for responding to spills at strategic locations on Canada's coasts (P. Vandenberg, Canadian Coast Guard, personal communication).

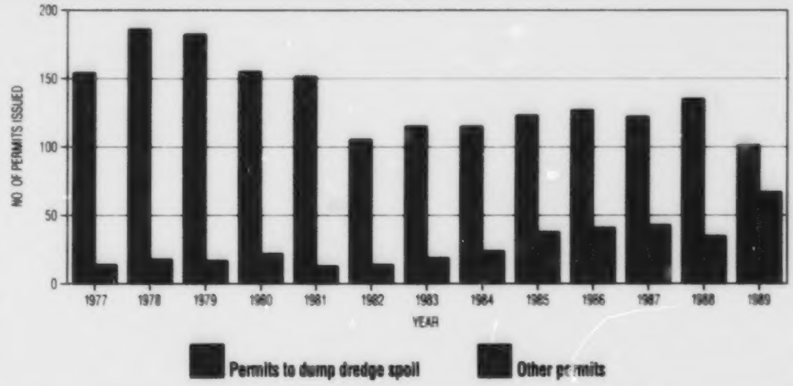
Ocean dumping

Ocean dumping is a federally regulated activity for the disposal at sea of certain types of materials at specific dump locations. However, many other types of waste, up to 80% of the oceans' total waste loading, originate on land and are not regulated under the ocean dumping provisions of the *Canadian Environmental Protection Act* (CEPA).

In 1989, 5.0 million cubic metres of dredged material and 131 500 t of fish-processing waste, or offal, were disposed of in Canada's marine waters. An average of 164 ocean dumping permits were issued annually between 1977 and 1989 in Canada (Fig. 4.2). Dredged material (primarily from harbours) makes up the largest proportion of approved permits. The number of permits issued for nondredged material, however, has increased significantly over the last five years. The largest single contributing factor to this increase is the number of permits to dump fish-processing waste. The increase in permit approvals for nondredged material does not reflect a significant increase in the amount of dumping, but rather an improved awareness, within the fish-processing industry, of the need for a permit. Other nondredged materials dumped into the ocean include scrapped vessels and excavation materials. Off the Arctic coast, 63 permits were issued between 1980 and 1990; about 106 million tonnes of dredged material, 1 200 t of excavation material, and 56 000 t of scrap metal were dumped (Environment Canada 1990*a*).

FIGURE 4.2

Ocean dumping permits issued in Canada, 1977–89



Note: Permits provide an indirect measure of stress on the marine environment from ocean dumping. The figures present a conservative estimate of the number of permits issued nationally; the Pacific region, for example, issues "general permits" that may authorize more than one load or use of more than one dump site. Indicators that reflect more precisely the effects of ocean dumping on the marine environment — such as the number of permits rejected annually as a result of potential marine environmental effects — will become available with implementation of a national database on ocean dumping.

Source: B. Kay and L. Porebski, Environment Canada, personal communication; Environment Canada (1990*a*).

When Environment Canada reviews permit applications for ocean dumping, the department considers, on a site-specific basis, the following environmental effects: toxicity to marine organisms, contamination of sediments or other materials, bioaccumulation, tainting or reduced marketability of resources (fish or shellfish), oxygen demand, habitat smothering, potential for odour, foaming, and release of debris, and possible disruption of economic activities such as fishing and navigation. The ocean dumping control provisions are designed to eliminate or minimize the potential environmental and economic impacts of ocean dumping activities. For example, the provisions ban or limit the disposal of deleterious substances, including mercury, cadmium, oil and grease, high-level radioactive wastes, persistent plastics, and various other toxic materials. Standards for control of ocean dumping reflect a commitment to protecting human health, marine life, and legitimate uses of the sea. In 1990, parties to the international London Dumping Convention, including Canada, agreed to phase out ocean dumping of industrial wastes by 1995 (B. Kay and L. Porebski, Environment Canada, personal communication).

The effects of ocean dumping on the Canadian marine environment, however, are not fully understood. Limited monitoring programs have not been adequate to fully measure short- and long-term effects. Improved programs for monitoring dump sites and evaluating substances to be disposed of at sea are being implemented and will provide answers to some of these questions (B. Kay and L. Porebski, Environment Canada, personal communication).

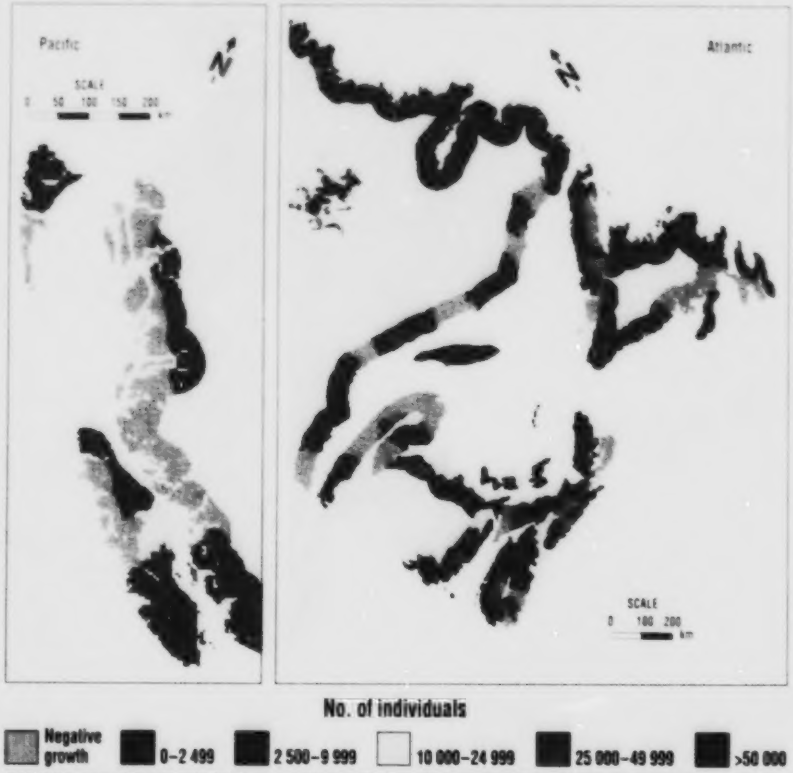
Coastal development

Burgeoning human populations in coastal areas are now recognized as a growing global problem. In Canada, the problem is less severe than in the eastern and southwestern United States and around the Mediterranean, for example, but it does occur (e.g., in and around Vancouver). Overall, in 1986, about 18% of Canada's population — or 4.5 million out of 25 million people — resided within 50 km of the coast (Fig. 4.3).

Between 1971 and 1986, population grew by about 30% on the Pacific coast, mainly around Vancouver (28%) and Victoria (32%). On the Atlantic coast, population increased about 10% between 1971 and 1986, with the

FIGURE 4.3

Population change within 50 km of the coast, 1971–86



Source: Statistics Canada, 1971–86 Census of population, Environment and Natural Resources Unit.

largest increases around St. John's (22%) and Halifax (18%). Such population growth is often the source of increased stress on marine ecosystems, as a result of sewage, industrial wastes, litter, and urban runoff.

Physical restructuring

Coastal developments, such as port facilities, houses, and other structures, put pressure on the marine environment. Human settlements and industries consume wetlands and other habitat. Since 1880, for example, building, diking, draining, and/or filling in intertidal and delta wetlands in the Fraser River estuary for human settlement purposes have resulted in the alteration of over 70% of shoreline habitat and 50% of the delta (Kennett and McPhee 1988).

Physical restructuring — the building of causeways, dams, breakwaters, and piers — can also alter flows of water and sediment and interrupt migration, spawning runs, and larval transport of fish and invertebrates. In Nova Scotia, construction of the Canso causeway changed the numbers and types of bottom-dwelling species in the Strait of Canso. A smaller causeway at Barrington Passage cut off the summer mackerel migration and destroyed lobster habitat (Eaton *et al.* 1986).

Dams on southern Quebec rivers have altered the flow of fresh water into the St. Lawrence estuary and gulf, resulting in changed salinity regimes and influencing biological productivity. The construction of the Annapolis Tidal Power Station on the Annapolis River, Nova Scotia, has changed currents and caused river erosion upstream. Human, fish, and bird populations, dependent on the river and associated coastal ecosystem, have been affected by this development (Wells and Rolston 1991).

Proposals to construct a fixed link between Borden, Prince Edward Island, and Cape Tormentine, New Brunswick (to replace ferry services across Northumberland Strait), have focused on bridge or tunnel construction. Projected environmental impacts of a bridge include physical interference with fisheries (delayed ice departure, for example, could affect migratory patterns of pelagic fish and groundfish) (Environmental Assessment Panel 1990).

The most spectacular effect of causeway and pier construction may be seen along the Bay of Fundy, where causeways on the tidal Petitcodiac and Avon rivers have resulted in heavy siltation and the creation of artificial mudflats (Amos 1977). The causeway at the Letang estuary in New Brunswick has inhibited the dispersion of wastes with a high biochemical oxygen demand (BOD) from a nearby sulphite pulp mill and degraded environmental conditions, forcing closure of shellfish beds (Wildish *et al.* 1974, 1988).

Expansion of industrial activities is the primary coastal development issue in the Arctic. Between 1959 and 1990, 167 dredging operations, associated with offshore exploration, were conducted in the southern Beaufort Sea, at Tuktoyaktuk Harbour, McKinley Bay, and Tuft Point (E. Porter, Environment Canada, personal communication). The construction of artificial islands, loading docks, and mine sites has resulted in short-term, localized increases in suspended sediment concentrations and turbidity, and some benthic habitats have been destroyed at dredging and dumping sites. Recovery of dredged areas and disposal sites to a level of productivity comparable with predisturbance levels usually takes several years (Thomas *et al.* 1985).

Hydroelectric development also threatens the health of arctic coastal ecosystems. One key concern is that modification of the annual discharge cycle of rivers causes changes to the coastal oceanographic regime (e.g., water temperature, ice, salinity, and turbidity), which in turn affects marine ecosystems. For example, hydroelectric development and changes in the annual freshwater discharge into arctic waters could affect the formation and transport of ice floes; the productivity of ice algae, which is important to fish larvae; the feeding habits of seal and whale populations; and the reproduction of seals. The creation of reservoirs also results in the release of mercury from flooded soils, contaminating fish and other aquatic life (see Chapter 3). These types of concerns apply to both existing and proposed hydroelectric developments.

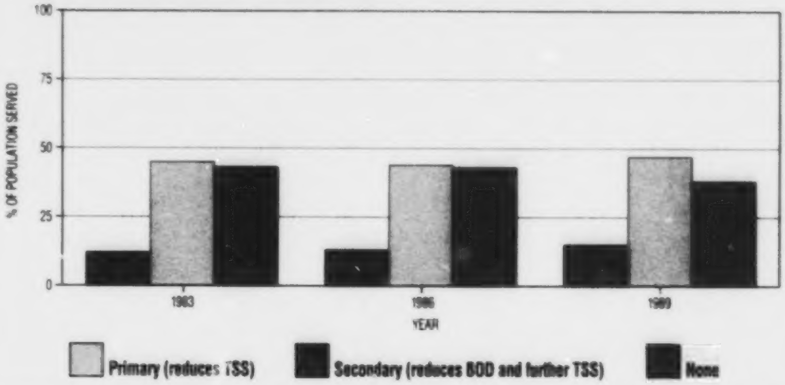
Disposal of municipal wastewater

About 200 million litres of untreated wastewater enter Halifax Harbour every day (Fournier 1990). Municipal wastewater is a major source of contaminants in the marine environment. The potential for these wastes to cause environmental damage is commonly measured in terms of biochemical oxygen demand (BOD) and total suspended solids (TSS). BOD results from the decomposition of organic waste and can threaten aquatic life by reducing the oxygen content of the water. TSS, which includes sand, grit, other nonbiodegradable materials, and human fecal matter, can alter benthic habitat and, in the last case, can cause fecal coliform contamination.

Nationally, as of 1989, about 47% of the coastal population living in communities of 1 000 or more was served by primary wastewater treatment, 15% by secondary treatment, and <1% by tertiary treatment; the wastewater of 38% received no treatment (Fig. 4.4).

FIGURE 4.4

Percentage of coastal population in centres of over 1 000 people served by wastewater treatment[a]

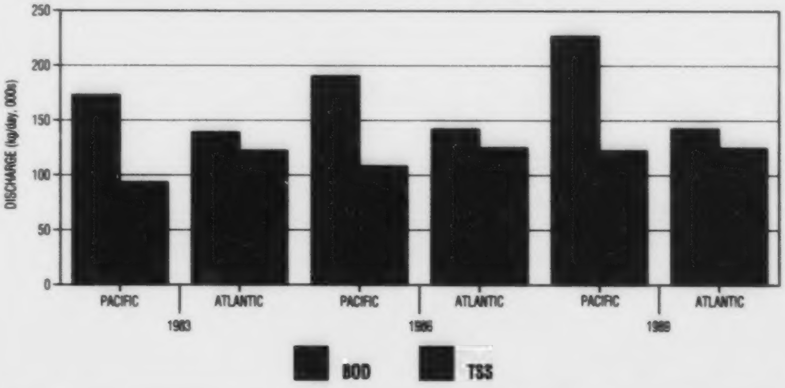


[a] Less than 1% of the coastal population in centres of over 1 000 people was served by tertiary treatment, which reduces nutrient content.

Source: Indicators Task Force (1991).

FIGURE 4.5

Biochemical oxygen demand (BOD) and total suspended solids (TSS) discharged daily in municipal wastewater effluents from coastal communities in centres of over 1 000 people



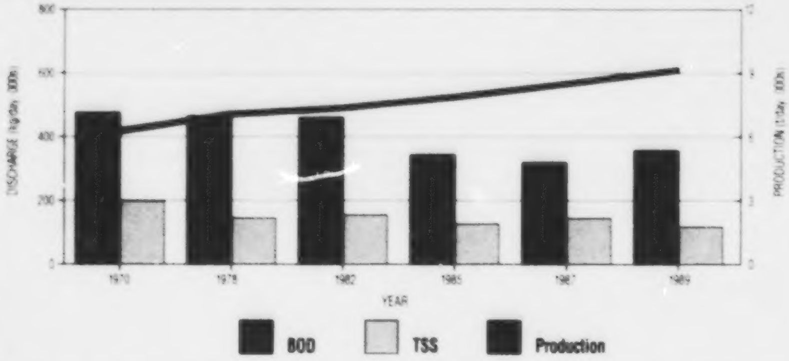
Source: Indicators Task Force (1991).

The release of disease-causing microorganisms into the marine environment has important economic and health impacts. Bacteria discharged in municipal wastewater are implicated in about half of shellfish area closures on the Atlantic and Pacific coasts and are responsible for the closure of swimming beaches. Agricultural runoff is another important source of this type of contamination (Indicators Task Force 1991).

On the Atlantic coast, BOD and TSS loadings remained fairly constant between 1983 and 1989, whereas they increased on the Pacific coast in response to the growth of Vancouver and Victoria (Fig. 4.5). BOD levels in 1989 were highest on the Pacific coast of Canada (227 000 kg/day versus 142 000 kg/day on the Atlantic coast), whereas loadings of TSS were similar on both coasts (Indicators Task Force 1991).

FIGURE 4.6

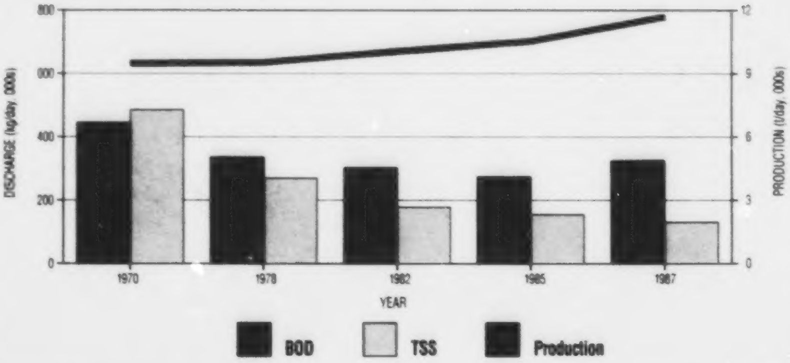
Biochemical oxygen demand (BOD) and total suspended solids (TSS) in wastewater discharged daily from pulp and paper mills to Atlantic coastal waters



Source: Indicators Task Force (1991)

FIGURE 4.7

Biochemical oxygen demand (BOD) and total suspended solids (TSS) in wastewater discharged daily from pulp and paper mills to Pacific coastal waters



Source: Indicators Task Force (1991).

Discharges from pulp and paper mills

Total suspended solids and biochemical oxygen demand

The production of pulp and paper generates large quantities of organic waste. The release of wood fibres and other materials reduces the oxygen content of water and can smother benthic habitats.

There are 20 pulp and paper mills on or near the coast in the Atlantic provinces. Most of these are older mills that were built without sufficient facilities for treatment of wastewater (Waldichuk 1988). Despite an increase of about 31% in pulp and paper production between 1970 and 1989, a combination of pollution control equipment and altered manufacturing processes enabled companies to reduce levels of BOD in wastewater released to the marine environment by about 25% (Fig. 4.6). Over the same period, TSS released to the ocean by Atlantic coastal pulp mills declined by 41% (Indicators Task Force 1991).

Ten pulp and paper mills discharge effluents into estuarine and coastal environments on the British Columbia coast. Between 1970 and 1987, whereas pulp and paper production per day increased by about 19%, BOD levels and TSS loadings declined by 27% and 73%, respectively, probably as a result of the installation of primary treatment systems at certain mills (Fig. 4.7).

In 1987, TSS loadings and BOD levels discharged daily from pulp and paper mills were similar on both coasts (Figs. 4.6 and 4.7) (Indicators Task Force 1991). In British Columbia, approximately 3 400 ha of the seafloor have been affected by wood fibre discharged by coastal pulp mills (Wells and Rolston 1991). Because gases produced in mats of fibre that accumulate on the sea bottom are toxic to oxygen-breathing organisms, recovery of benthic habitat may span several decades.

In Alberni Inlet, Vancouver Island, oxygen depletion in deeper waters has dangerously reduced the sockeye salmon run (Waldichuk 1987). Similarly, major fish stocks, beginning with pink salmon, may have been lost during the operation of the sulphite pulp mill at Port Alice on Neroutsos Inlet. About 18 km of the inlet are unsuitable for marine life — because of depressed dissolved oxygen concentrations from BOD discharges — during certain periods of the year. It will be some years before the conditions in the inlet have recovered sufficiently to allow the return of a small run (about 6 000) of chum salmon. Water quality in Neroutsos Inlet improved dramatically with waste treatment in 1977, worsened somewhat in 1985, and is currently stable (Wells and Rolston 1991).

Dioxins and furans

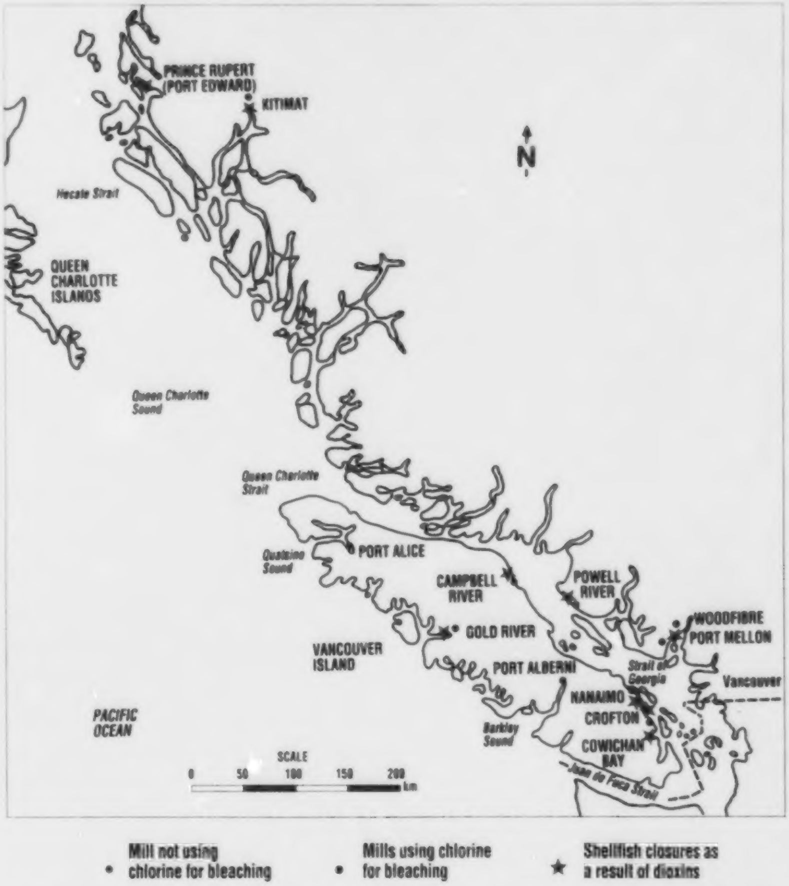
Pulp and paper mills and associated industries along the Pacific coast are also major sources of toxic contaminants. A serious pollution problem is the release of dioxins and furans.

The major marine sources of these highly toxic chemicals are pulp and paper mills that use chlorine for bleaching and use of pentachlorophenol for wood preservation by the lumber industry. Some commercial and recreational fisheries for crabs, prawns, shrimp, and oysters have been closed because of these contaminants. There is a geographical overlap amongst many of these fisheries closures, although the area closed to crab fisheries predominates. Prior to August 1991, the sum of the closures for all affected species covered a total of 97 970 ha (about 1% of the B.C. coastline) at nine sites adjacent to coastal pulp mills and one sawmill (Fig. 4.8). Dioxins and furans have accumulated in the fatty tissues of these seafood species. High levels have also been found in livers of some finfish samples and in seabird eggs. In 1987, for example, the heron colony at Crofton on the east coast of Vancouver Island, near a pulp and paper mill, failed to produce young. At the same time, levels of 2,3,7,8-TCDD — the most toxic form of dioxin — in sampled heron eggs had increased to 210 ppt from 66 ppt in 1986 (Elliott *et al.* 1989). Health and Welfare Canada has advised people to limit their consumption of two duck species (Common Merganser and Surf Scoter) located near the pulp mill at Port Alberni, because of high levels of dioxins found in their livers. Seven mills in Atlantic Canada also use chlorine bleaching and may be the source of several thousand tonnes of chlorinated organic compounds annually (T.E. Ruthman and D. Haliburton, Environment Canada, personal communication).

In response to growing public concern about dioxins and furans, the federal government initiated a national sampling program in 1988. At present, there are 48 Canadian mills that use chlorine to bleach pulp. Revised Pulp and Paper Effluent Regulations under the *Fisheries Act* and new regulations to be passed under CEPA will become law early in 1992. These regulations will require that dioxins and furans be undetectable in effluents from pulp mills that use chlorine bleaching. New mills must comply immediately; existing mills have until 1994 to comply. A further regulation under CEPA will restrict the sale and use of defoamers and wood chips used in the papermaking process that give rise to the formation of dioxins and furans. These reforms will be fully in force by 1994. The new regulations will also require all mills to reduce their loadings of BOD and TSS into the marine environment. Current federal regulations designed to control liquid discharges from pulp and paper mills apply only to mills built, expanded, or altered after 1971 — a mere 13 of the 154 total (T.E. Ruthman and D. Haliburton, Environment Canada, personal communication).

FIGURE 4.8

Locations of pulp mills and areas closed to commercial fishing for shellfish because of dioxin contamination along the British Columbia coast, 1990


PRINCE RUPERT
(PORT EDWARD)
KITIMAT
N
Hecate Strait
QUEEN CHARLOTTE ISLANDS
Queen Charlotte Sound
Queen Charlotte Strait
Quatsino Sound
PORT ALICE
CAMPBELL RIVER
POWELL RIVER
WOODFIBRE
PORT MELLON
GOLD RIVER
VANCOUVER ISLAND
PORT ALBERNI
Strait of Georgia
Vancouver
NANAIMO
CROFTON
COWICHAN BAY
Barkley Sound
Juan de Fuca Strait
PACIFIC OCEAN
SCALE
0 50 100 150 200
km
Mill not using chlorine for bleaching
Mills using chlorine for bleaching
Shellfish closures as a result of dioxins

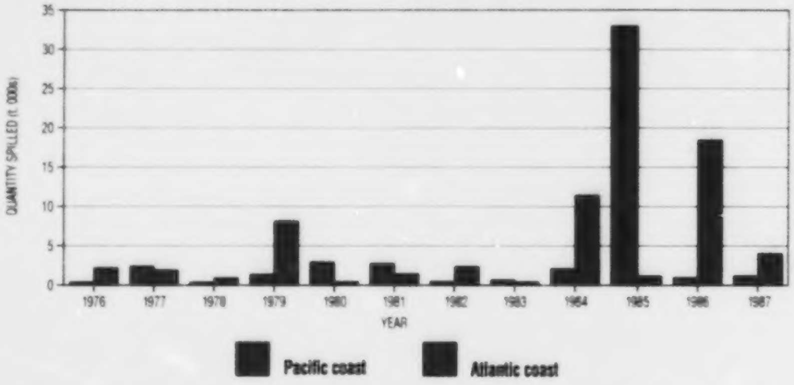
Source: M. Waldichuk, Department of Fisheries and Oceans, personal communication.

TYPES OF CONTAMINATION

Contaminants may enter the marine environment from many anthropogenic sources, including industrial discharges, spills, inputs from coastal and offshore oil and gas development, municipal wastewater discharges, runoff from agricultural and urban areas, ocean dumping, and long-range atmospheric transport. Six important types of contamination known to affect marine environmental quality

FIGURE 4.9

Significant[a] spills in Canadian marine waters, except in the Arctic, 1976–87



[a] Significant spill is one in which the spilled material exceeds 1 t.

Source: Indicators Task Force (1991).

in Canada are nutrients, spills, PAHs, heavy metals, synthetic chlorinated organic compounds, and persistent litter and debris.

Nutrients: eutrophication and natural toxins

Nutrients such as nitrogen and phosphorus are essential to marine life; however, they become a problem when too great a quantity enters the water. Sources of nutrients in nature are decaying plants and animals, leaching from rocks and soils, and atmospheric deposition. The human sources that often overload the natural system are municipal sewage, fertilizers and animal wastes in runoff, and wastewater from industry, especially the food-processing industry.

Eutrophication occurs when elevated levels of nitrogen and phosphorus stimulate excessive growth of phytoplankton and other marine plants. When plants die and decompose, life-supporting oxygen in the water is depleted. In extreme cases, oxygen depletion may cause widespread mortality among marine organisms. Salmon kills have occurred in streams draining into Boundary Bay, British Columbia, mainly as a result of excessive algal growth from overenrichment and subsequent die-down, decay, and oxygen depletion. Decomposing plankton blooms in the Strait of Georgia, British Columbia, have caused mortality among fish stocks as a result of suffocation (Evelyn 1972) and irritation of the gills (Brett *et al.* 1978; Pennell 1988).

Some forms of phytoplankton in bloom conditions produce toxins, which may contaminate shellfish, making them unfit for human consumption. For example, paralytic shellfish poisoning (PSP) is caused by toxins from certain species of dinoflagellate phytoplankton. Although the dinoflagellates occur naturally, outbreaks of PSP appear to be increasing in frequency, perhaps because of eutrophication of coastal marine ecosystems (Waldichuk 1988). A recent dinoflagellate bloom and associated PSP outbreak along the Gaspé coast in Quebec may have been due to nutrients from sewage outfalls along the St. Lawrence River (Messieh and El-Sabh 1988).

In November 1987, an outbreak of amnesic shellfish poisoning, involving people who ate cultured mussels from Prince Edward Island, led to a temporary ban on harvesting of all Atlantic clams, mussels, oysters, and quahaugs. By the time the ban was lifted in early January 1988, a total of 129 cases of mussel poisoning had been reported, with two casualties (Waldichuk 1988). The deaths were caused by a toxin, known as domoic acid, produced by the diatom *Nitzschia pungens* (Subba Rao *et al.* 1988). The *Nitzschia* bloom in waters off eastern Prince Edward Island occurred when nutrient levels were high, possibly as a result of agricultural fertilizers washed into the sea, and growing conditions for the diatom were ideal (Bates *et al.* 1989).

Spills

Between 1976 and 1987, 171 significant (in excess of 1 t) marine spills occurred on Canada's Atlantic coast (a total of about 52 000 t), and 180 significant spills occurred on the Pacific coast (about 48 000 t). The volume of material spilled on the Atlantic and Pacific coasts fluctuated widely from year to year from 1976 to 1987; no significant trend upward or downward is evident[2] (Fig. 4.9).

Petroleum spills made up 67% of the number of reported marine spills on the Pacific coast. On the Atlantic coast, 88% of the number of reported marine spills were petroleum (Indicators Task Force 1991). In terms of volume, petroleum accounted for 53% of the quantity of all material spilled into marine waters in the Atlantic provinces between 1976 and 1987. Industrial wastes represented a further 44% of the quantity of spilled material. Spills occurred most frequently in harbours, with oil and chemicals (PCBs and pesticides) being the most common substances spilled. Ships and leaking storage containers were the major sources (Eaton *et al.* 1986).

On the Pacific coast, industrial waste made up 79% of the total amount spilled (about 48 000 t) between 1976 and 1987 (Indicators Task Force 1991). Between 1980 and 1984, transport accounted for 12%, the pulp and paper industry for 8%, fishing for 6%, and the petroleum-petrochemical industries for 6%. The origin of 42% of recorded spills between 1980 and 1984 was unknown. Reported spills from pulp and paper operations increased from 4 to 92 between 1984 and 1988 (Wells and Rolston 1991), largely as a result of improved reporting. In 1988, 574 incidents were reported on the west coast, most of a minor nature (less than 1 t). By 1990, this number had risen substantially (Wells and Rolston 1991). One recent event, the *Nestucca* spill, resulted in adverse ecological and economic effects (see Box 4.1).

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[2] Statistics about spills are difficult to interpret because of a recent trend to report smaller spills more frequently.

The volume of traffic carrying toxic or harmful substances is a major concern for ports and approaches, especially given recent west coast experience with the *Nestucca* oil spill. The Vancouver Port Corporation reports that almost 1 million tonnes of petrochemicals are shipped through Vancouver to offshore markets on an annual basis. In addition to large tankers, about 8 250 smaller tankers and barges moved through the port in 1988 (Lyons 1989).

Maritime traffic and runoff and sewage from urban areas accounted for the most spills and environmentally significant accidents in the St. Lawrence estuary and gulf. On an annual basis, about 200 oil slicks are reported for the lower river and estuary (between Cornwall and the western tip of Anticosti Island). Between 1980 and 1984, an average of 54 spills occurred as a result of marine accidents, including ship groundings and collisions (Wells and Rolston 1991).

Impacts of oil pollution

"There are three myths about oil spills that need clearing up," wrote oil spill expert John H. Vandermeulen (1990). "That oil spills can be controlled. Not so. Second — that oil spills can be cleaned up. Not so. Third — that damaged environments are doomed. Wrong again."

Nonetheless, in the short term at least, there are losses. Oiling of seabirds causes their feathers to mat, losing their insulation value. Flight becomes more energy consuming, and swimming and diving are impaired. "An increasing spiral of debilitation begins which usually ends with the bird's death," concludes seabird biologist, R.G.B. Brown, in "Birds, oil and the Canadian environment" (Environment Canada 1982).

Large amounts of oil are spilled in tanker accidents, such as the grounding of the *Exxon Valdez*, but chronic, small spills, deliberate discharges on the high seas, and leakage — associated with offshore drilling, marine shipping,[3] small boat traffic, and the storage and handling of petrochemical products — are also major sources of marine pollution. Oil is also washed off city streets and parking lots into the sea. Gasoline and oil products used by automobiles are sometimes discharged through sewer systems because of the lack of adequate waste reception facilities in many towns and cities. Fishery workers and recreational boaters also have difficulties disposing of oily wastes onshore and often use the ocean as a readily available dump site.

It is generally recognized that the immediate effects of oil pollution are more or less localized. Impacts near sources or major spills include direct toxic effects on plants and animals, smothering of shoreline and benthic habitats, tainting of fish stocks that support commercial fisheries, and seabird mortalities. Piatt *et al.* (1985) conservatively estimated, for example, that between 20 000 and 100 000 oil-related seabird deaths occur each year off the coast of Newfoundland.

The international group of experts on the scientific aspects of marine pollution (GESAMP 1990) indicated that, except in the immediate vicinity of sources or major spills, oil in the sea is generally found at concentrations too low to pose immediate threats to marine organisms. However, long-term impacts of oil pollution and the recovery of oiled habitats, especially in arctic areas (see Chapter 15), are not fully understood.

One of Canada's early major oil spills, for example, occurred in February 1970 when the tanker *Arrow* ran aground in Chedabucto Bay, Nova Scotia, with a full load of Bunker C (a heavy fraction of crude oil, used in heating plants), resulting in a spill of about 15 000 t. Recent analyses have focused on the long-term persistence and potential ecological impacts of tar and other residues of the original oil at one particular study site, Janvrin lagoon. The shoreline was heavily oiled in 1970, and to this date oil sheens are visible there on warm summer days. Scientists have visited the site and noted recognizable Bunker C tar on the lagoon shorelines, with hydrocarbons from such tar still mobile and available to intertidal biota. This 20-year-old sediment-covered oil could persist for another decade, although its toxicity is diminishing steadily (J.H. Vandermeulen, Bedford Institute of Oceanography, personal communication).

Polycyclic aromatic hydrocarbons

Among the burden of chemicals in the beleaguered St. Lawrence beluga are PAHs, discovered in brain tissue (Wells and Rolston 1991). PAHs are a group of hydrocarbons found in petroleum. They may also have other natural sources. They enter the marine environment by many routes: via petroleum spills and leaks, especially from tanker accidents and offshore drilling for crude oil; via runoff, leaching, and disposal of refinery effluents; and via atmospheric transport, as a by-product of incomplete combustion of petroleum hydrocarbons (National Research Council of Canada 1983).

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[3] "Most of the oil entering the oceans of the world from ships does so as the result of a deliberate decision by a ship's captain, and not by reason of an accident. These deliberate discharges are the result of pumping out bilge water mixed with leaked fuel oil or lubricating oil, or of discharging overboard ballast water containing residual fuel oils, or discharging the washings from fuel or cargo tanks over the side. Generally speaking, this is done on the high seas. The long-term effects of the practice are unknown. Generally, no oil reaches the shore, and such overboard discharges pass unnoticed. Occasionally, however, these deliberate discharges of oil hit our shores" (Anderson 1989).

The PAH compounds with higher molecular weights can accumulate in the fatty tissues of marine organisms. Each species takes up each PAH compound at its own rate; thus, health effects vary. In fish, PAHs can cause liver enlargement and affect reproduction (National Research Council of Canada 1983).

Aluminum smelting plants on the Saguenay River have contributed to high levels of lead, zinc, and mercury, as well as PAHs, in sediments (Martel *et al.* 1986; Smith 1988). Mussels, as well as beluga, from the Gulf of St. Lawrence were found to have elevated levels of PAHs (Waldichuk 1988). The sediment levels remain high, although federal regulations have resulted in the reduction of contaminant inputs over the past 10 years.

Vancouver Harbour has shown elevated concentrations of sediment contaminants, including PAHs and certain trace metals (Goyette and Boyd 1989). PAH levels were highest in Port Moody Arm. In 1987, up to 75% of the larger size English sole sampled (mean length 32 cm) in Port Moody Arm had precancerous or cancerous liver lesions. A link between sediment-associated PAH and prevalence of English sole liver lesions is suspected, based on studies conducted by Malins *et al.* (1984) and Myers *et al.* (1987) in Puget Sound, Washington State.

Levels of PAHs in Tuktoyaktuk Harbour have been high enough to implicate them as a major cause of liver lesions in arctic flounder (Thomas and Hamilton 1988). There have been numerous small spills of oil and other wastes at Tuktoyaktuk. Because the area supports subsistence fishing, there are concerns about long-term impacts on fish (Wells and Rolston 1991).

BOX 4.1

The *Nestucca* oil spill

In December 1988, off the coast of Washington State, the tug *Ocean Service* was attempting to recover its tow, the barge *Nestucca*, when the two vessels collided. The *Nestucca* was holed, and its cargo of Bunker C oil began to leak into the sea. The barge was towed about 40 km offshore where temporary repairs were made, but it left a swath of oil — about 875 t — in its wake.

Ocean currents carried the slick in a generally northward direction for hundreds of kilometres, first oiling sections of the coast of Washington, then sections of the coast of Vancouver Island. The oil came ashore at various locations, including at the southern tip of the island, in the vicinity of Sooke, and near the northern tip at Cape Scott. About 2 or 3 km were considered "heavily oiled," whereas 150 km were "moderately" or "lightly" oiled (Fig. 4.B1).

The most apparent impact of the *Nestucca* oil spill was the death of some 46 000 seabirds in British Columbia and Washington. Dead birds were found along the entire length of Vancouver Island from Sooke to Cape Scott, including the shorelines of Pacific Rim National Park. There was widespread, low-level contamination of sandy beaches, mortality and damage to plants within the intertidal zone, and oiling of salt-marsh habitat. The spill also created acute concern about damage to spawning areas of economically important species such as herring and effects on salmon and groundfish.

The *Nestucca* oil spill, and related events such as the much larger spill of the *Exxon Valdez* in Alaska in 1989, heightened concern about shipping accidents and the country's ability to prevent, and respond effectively to, such events. This led to two important initiatives: an internal federal review of marine spill prevention and response capabilities, and an independent public review, which released its final report in September 1990. Acting on the recommendations of the reviewers is an important challenge for all agencies that manage Canadian marine areas and resources.

Heavy metals

Metals occur in the marine environment both naturally and as a result of human activities. Many are essential to life, but others, such as lead, mercury (as methylmercury, an organic form), and cadmium, serve no known metabolic function and, in fact, can be highly toxic.

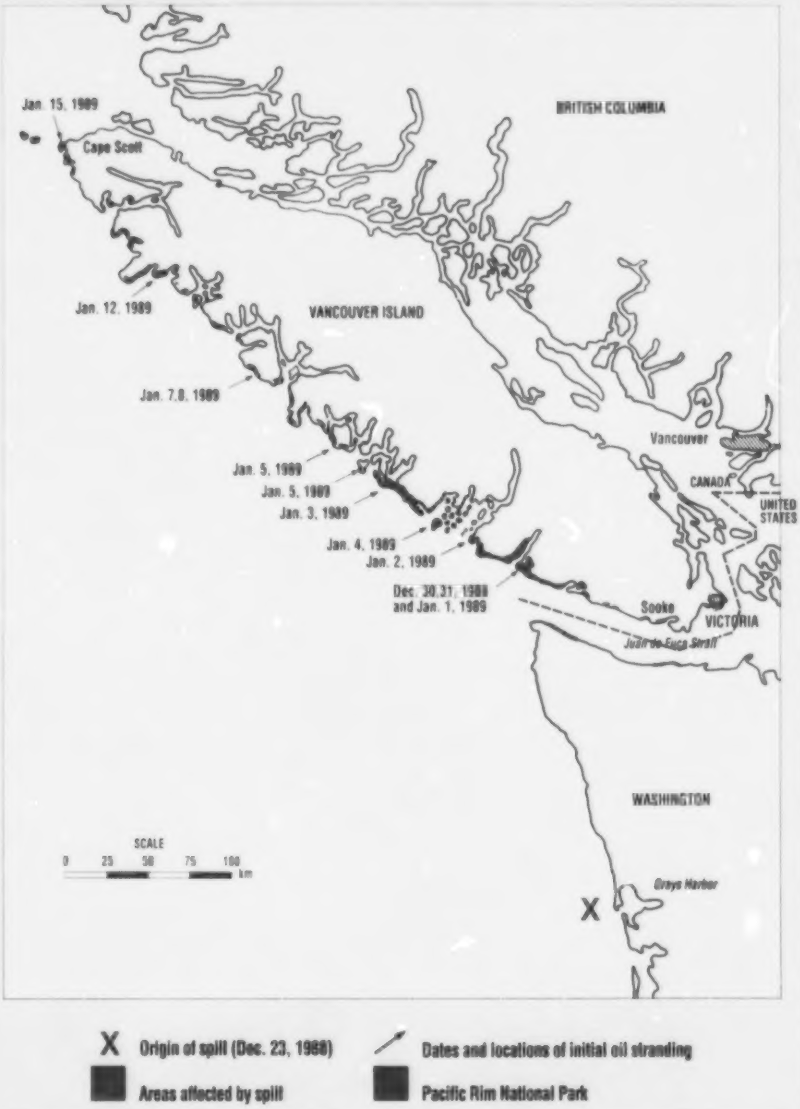
Sources of metal pollution include offshore oil and gas development, industrial effluents, discharges of municipal wastewater, mining and loading facilities, ocean dumping, and volatile emissions from incineration and combustion that reach the ocean via the atmosphere. In sediments, trace metals tend to be bound in inorganic forms to rock particles eroded from ocean cliffs or mountainsides. However, in many estuarine environments, trace metals may precipitate from solution as organic compounds and become biologically available (Moore and Ramamoorthy 1984). In most environmental studies, only total concentrations of metals (e.g., inorganic mercury plus methylmercury) are measured; hence, the amount that is bioavailable is not known. Moreover, the capacity of humans and other organisms to bioaccumulate and tolerate given concentrations of different metals varies widely.

Research conducted in British Columbia indicates that invertebrates living in close association with organic sediments containing high levels of trace metals may incorporate them into their tissues (Kay 1986), and, subsequently, such metals may — or may not — pass through the food chain to the highest levels in top predators, including commercial fish species (Wells and Rolston 1991).

One source of heavy metals in the marine environment is mine tailings. Approximately 8 340 ha of benthic habitat have been smothered by non-toxic tailings from coastal mines in British Columbia, most of which are

FIGURE 4.31

Areas affected by the *Nestucca* oil spill


Jan. 15, 1989
Cape Scott
BRITISH COLUMBIA
Jan. 12, 1989
VANCOUVER ISLAND
Jan. 7,8, 1989
Jan. 5, 1989
Jan. 5, 1989
Jan. 3, 1989
Jan. 4, 1989
Jan. 2, 1989
Dec. 30,31, 1988 and Jan. 1, 1989
Vancouver
CANADA
UNITED STATES
Sooke
VICTORIA
Juan de Fuca Strait
WASHINGTON
SCALE
0
25
50
75
100
km
Grays Harbor
X
X Origin of spill (Dec. 23, 1988)
Dates and locations of initial oil stranding
Areas affected by spill
Pacific Rim National Park

Source: Duval *et al.* (1989); Harding and Englar (1989).

now closed. However, one coastal mine (the Island Copper Mine) continues to operate with unconfined disposal of tailings into the waters of Rupert Inlet on the northwest coast of Vancouver Island. Here, tailings have smothered benthic communities up to tens of kilometres from the outfall (Wells *et al.* 1987).

Fortunately, recovery of ecosystems from exposure to nontoxic mine tailings is known to be relatively rapid. For example, the benthos at Alice Arm began to recover within a few years of a mine closure, although the composition of benthic communities changed and species favouring soft-bottom substrates such as mud or loose sediment came to predominate (Brinkhurst *et al.* 1987).

Smelting operations in Atlantic Canada have resulted in localized areas of metal pollution. The lead smelter near Belledune, New Brunswick, for example, was responsible for cadmium pollution in the 1970s (Waldichuk 1988), resulting in the closure of a lobster fishery and contamination of mussels as far as 20 km down the coast (Hildebrand 1984). Since 1981, however, metal concentrations in the liquid effluents have been reduced by 97% as a result of an improved treatment system (Uthe *et al.* 1986).

Cape Breton's coal mines discharge their wastewater and runoff directly into coastal waters (Eaton *et al.* 1986). Because of the high sulphur content of the coal, the wastewater is highly acidic, resulting in higher solubility of metals, which, in turn, may lead to bioaccumulation of metals in benthic fauna (Waldichuk 1988).

Mercury contamination of marine sediments and biota has been associated with discharges from chlor-alkali plants in Quebec, New Brunswick, Nova Scotia, and British Columbia (Smith 1988; Allan 1988; Loring 1988). Since regulations were introduced in 1972 to control levels of mercury emissions in the marine environment, however, levels have declined (Wells and Rolston 1991). Regulations introduced in 1971 reduced effluent mercury by 80% by the mid-1980s. Cossa and Desjardins (1984) reported a 20-fold decrease in mercury levels in shellfish in the Saguenay River since the 1970s. However, high levels of mercury have persisted in the bottom sediments of the St. Lawrence estuary, Saguenay River, and Restigouche River.

Mine sites at Polaris Bay on Little Cornwallis Island and Nanisivik on Baffin Island, both in the Northwest Territories, showed elevated levels of zinc and lead near outfalls and loading docks. Elevated levels of mercury, lead, zinc, cadmium, nickel, and copper have been detected near offshore well sites for petroleum exploration, although concentrations usually cannot be distinguished from background levels 100 m from the well, depending on local currents (Thomas *et al.* 1984; Barchard and Mahon 1986).

Synthetic chlorinated organic compounds

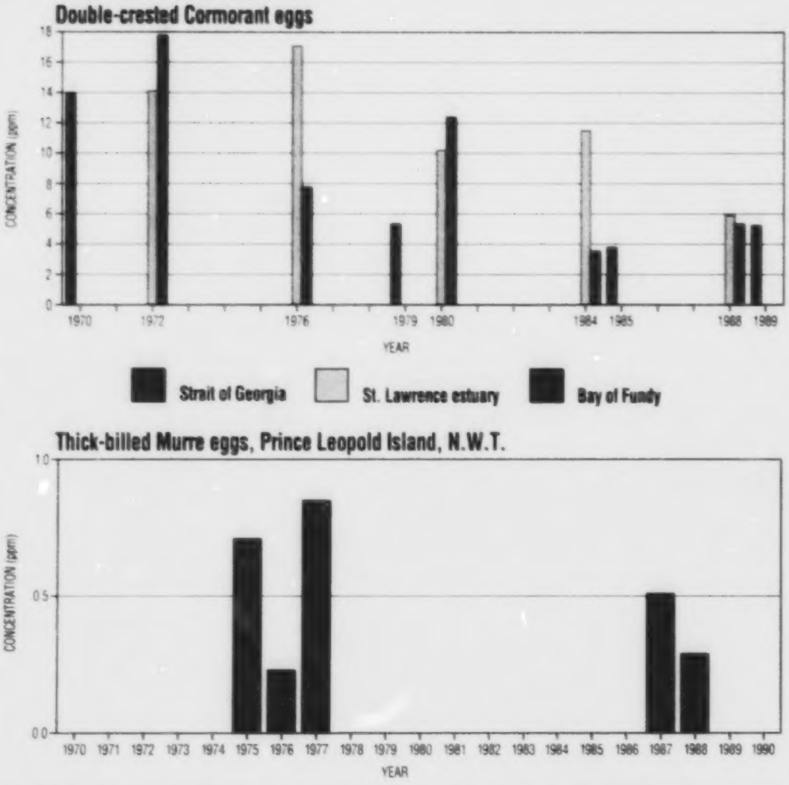
PCB levels in St. Lawrence belugas are comparable with those found in populations of marine mammals in Europe that have experienced reproductive dysfunction and population declines (Wagemann and Muir 1984). Because belugas feed on a variety of food, including fish and invertebrates, they have accumulated high levels of the chlorinated organic chemicals with which their prey are contaminated (D. Muir, Department of Fisheries and Oceans, personal communication).

Synthetic chlorinated organic compounds enter marine waters in agricultural runoff, at sewer outfalls, in wastewater from pulp and paper mills and other industries, and from spills on land or at sea. In addition, long-range atmospheric transport carries them to Canadian waters from sources as far away as Europe and Asia. DDT, PCBs, and toxaphene are generally the most prevalent in the marine environment. Others include dioxins and furans (already discussed) and the pesticides mirex, dieldrin, chlordane, and tributyltin — a compound in antifouling paints that prevents growth on the hulls of boats. The potential effects of chlorinated organic compounds on marine life include growth retardation, reduced reproduction, and diminished resistance to disease (Organisation for Economic Co-operation and Development 1991).

There are several sources of chlorinated organic compounds along the Atlantic coast. In the 1950s and 1960s, eastern forests were extensively sprayed with DDT. An estimated 5.7 million kilograms of this pesticide were used annually in New Brunswick during this period, with lesser amounts used in Quebec, Prince Edward Island, and Nova Scotia (Noble and Elliott 1986). Public concern resulted in the Canadian government severely restricting the use of DDT in Canada in the early 1970s. As of January 1, 1991, the sale and use of DDT is no longer permitted. The development of more selective and less persistent chemicals, resulting in a trend towards the use of biological controls, including the bacterial pathogen *Bacillus thuringiensis*, evolved through the 1980s (see Chapter 10).

FIGURE 4.10

PCB levels in seabird eggs on the Atlantic, Pacific, and Arctic coasts, selected years 1970–89



Source: Indicators Task Force (1991).

The Atlantic coast still receives substantial amounts of chlorinated organic compounds and other contaminants through long-range atmospheric transport from the main industrial and agricultural areas of the United States and Canada. The St. Lawrence River, which accumulates runoff from agriculture and wastewater from the industries along its shores, contributes large quantities of these toxic substances to the Atlantic Ocean (Noble and Elliott 1986).

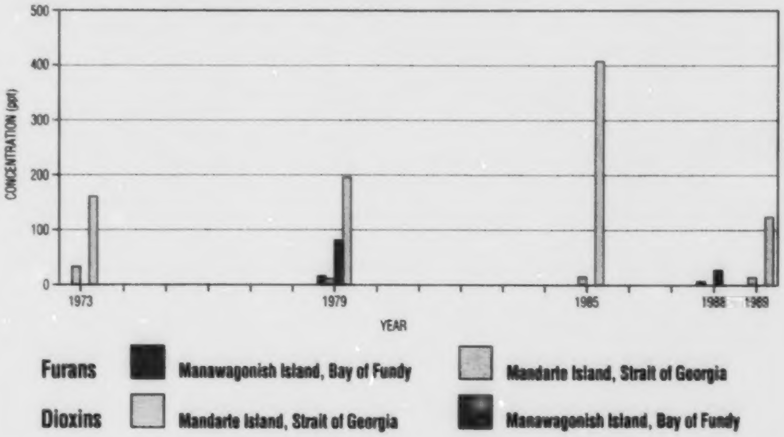
Atmospheric pollution from Asia, Europe, and North America reaches the Arctic Ocean; ocean currents and river discharges are also important pathways for pollutants. In studies of arctic mammals and fish, Norstrom and Muir (1988) found chlorinated organic compounds to be highest in Hudson Bay samples, intermediate in Baffin Bay samples, and lowest in those from the high Arctic. Between 1969 and 1984, chlordane levels in polar bear fat increased fourfold, whereas DDT levels remained the same (Norstrom *et al.* 1988).

Because of bioaccumulation, not only can these toxic chemicals be hazardous for wild animals at the top of the marine food chain, they also pose potential risks for humans who use these animals for food. Recent studies of PCB concentrations in food among residents of Broughton Island showed that 13.6% of the surveyed population who reported Inuit food consumption ingested more than the Canadian conditional tolerable daily intake of PCBs, set by Health and Welfare Canada at 1 µg per kilogram of body weight (Jensen 1990) (see Chapter 15, Box 15.2). Fat-rich marine mammals, particularly seals, narwhals, and other whales, are important to native diets and are believed to be the predominant source of PCBs in human tissues (Wells and Rolston 1991).

As part of the attempt to keep track of trends in toxic contaminants biomagnifying up the food chain, various seabird species are used as monitors. Concentrations of toxic chemicals, such as PCBs and DDT, in the eggs provide useful information about contaminant levels in the marine environment generally. Figures 4.10 and 4.11 show the trends for contaminants in eggs of two species of seabirds from coastal sampling sites. Concentrations of chlorinated organic compounds in the eggs of seabirds from the St. Lawrence estuary indicate that the region continues to be one of the most contaminated marine areas in Canada, followed by the Bay of Fundy, the Strait of Georgia, and the west coast of Vancouver Island. Chlorinated organic residues in seabird eggs sampled off Newfoundland, off the Arctic Islands, and along the northern coast of British Columbia are relatively low in comparison (Noble 1990).

FIGURE 4.11

Dioxin and furan levels in eggs of Double-crested Cormorants on the east and west coasts, selected years 1973–89



Source: Indicators Task Force (1991).

Persistent litter and debris

Discarded or lost plastics are causing the deaths, by entanglement or ingestion, of an estimated 2 million seabirds and 100 000 marine mammals in the world's oceans each year (Conner and O'Dell 1988). The often fatal predicament of seals, seabirds, turtles, and fish yoked and harnessed in plastic debris and nylon nets is a shameful indictment of the throwaway society — and more durable plastics are thrown away each year.

Quantities of litter are increasing in the ocean because of a growing population and greater use of plastic, especially disposable products. Plastics are designed to be strong, lightweight, and durable. Because of their persistence and buoyancy, however, they represent a growing proportion of the debris accumulating in the marine environment.

Studies of litter accumulation on Sable Island, 160 km off the coast of Nova Scotia, found that plastics represented nearly 94% of the total volume of the litter (Z. Lucas, private contractor, Halifax, personal communication). Plastic debris and ghost nets (lost or abandoned fishing nets) can entangle marine organisms. Piatt and Nettleship (1987) reported that deaths of harp seals, harbour porpoises, and harbour seals were unintended results of commercial fishing off Newfoundland. In the Arctic, plastic debris is largely associated with hunting and fishing camps and with shipping. Disposable diapers, empty oil containers, garbage bags, six-pack yokes, and spent shotgun shells are common forms of domestic refuse found in arctic coastal waters (Buxton 1989).

The problem of plastic debris has additional economic implications for commercial fishing and other marine activities. For example, the cost and time involved in vessel and gear repairs may be substantial. A Japanese study estimated that repairing damage to fishing vessels caused by debris blocking cooling systems and entangling propellers costs in the order of $70 million annually (Takehama 1989, cited in Buxton 1989). The coastal tourism industry is also at risk when beaches are sullied with litter.

ATMOSPHERIC CHANGE

As major components of the Ecosphere, the world's oceans and atmosphere are inextricably linked, primarily through an exchange of heat and gases. Oceans absorb carbon dioxide from the atmosphere (see Chapter 22), making them the largest reservoir of carbon in the global carbon cycle. Thus, changes in the properties and composition of the atmosphere have implications for the world's oceans. Important changes are occurring — increases in greenhouse gas concentrations, especially carbon dioxide; a general warming of the atmosphere near the Earth's surface; and a decline in the concentrations of stratospheric ozone.

Carbon dioxide

Of the 6–7 billion tonnes of carbon produced each year through the burning of fossil fuels and deforestation, up to one-half appears to be absorbed by the oceans. Depending on physical oceanographic features and primary productivity, some oceanic areas are sources of carbon dioxide, whereas others are sinks. The oceans exchange about 15 times as much carbon dioxide as human activities produce annually and store about 50 times more carbon than does the atmosphere (Williamson and Gribbin 1991).

The manner in which the ocean recycles carbon is only very generally understood. What is lacking is detailed knowledge of all the processes involved and of the rates of transformation between the various oceanic reservoirs where carbon is stored, to the level needed to support improved predictions of global warming. Carbon enters the ocean by gas exchange across the air/sea interface and by the supply of dissolved organic and inorganic carbon from rivers. Some of this carbon is incorporated into the marine food chain by way of microscopic plants. It is also transported from the upper layers of the ocean to the deep layers by two general processes: the transport of dissolved organic and inorganic carbon by sinking of water from the surface, and the sinking of particles of biological origin from the surface into the deep sea. These exchanges take from years to hundreds of years, depending on the processes involved. The first response of the ocean to increases in atmospheric carbon dioxide is to increase the amount in solution and thus over time transport an increasing amount into the deeper oceanic layers. Canadian scientists are participating in an international project, the Joint Global Ocean Flux Study, which is aimed at understanding the role of the oceans in the global carbon cycle.

On a per capita basis, Canadian emissions of carbon dioxide and other greenhouse gases were third highest among countries that belonged to the Organisation for Economic Co-operation and Development in 1987. Globally, anthropogenic carbon dioxide emissions have more than tripled since 1950. Responsibility for these emissions is widely shared among major world regions. Canada recently announced its intention to stabilize emissions of carbon dioxide and other greenhouse gases at 1990 levels by the year 2000 (Indicators Task Force 1991).

Temperature increase

Since about 1900, mean global air temperatures have risen about 0.5°C. An international panel of experts recently concluded that temperatures could rise a further 1°C by 2025 and 3°C by 2100 if no significant measures are taken to control rising concentrations of greenhouse gases such as carbon dioxide. Temperature increases are expected to be greatest at high latitudes. However, our knowledge of the arctic climate, especially over the ocean, is limited. Evidence that increases in ocean temperatures are occurring is strongest from the Pacific coast. Daily surface temperature measurements for several sites on the British Columbia coast date back to 1915. At stations exposed directly to the Pacific Ocean, warming trends equivalent to 0.4°C per century have been recorded (Freeland 1990).

The rise may seem small, but the consequences of a continuing trend are of real concern. A northward shift of warm ocean water would have major ecological and economic consequences. For example, the Fraser River stocks of sockeye salmon are now at the southern limit of the species' geographical distribution. Global warming could also cause a general warming and freshening of the continental shelf waters in eastern Canada, leading to shifts in the geographic distribution of several commercially important groundfish stocks, especially those at the extreme limits of their range (Frank *et al.* 1988). Pelagic species that make large seasonal migrations could be expected to arrive earlier and depart later (Mysak and Lin 1990).

Sea-level rise

Scientists agree that global warming would lead to a rise in the level of the ocean as a result of thermal expansion of the water and melting of the glacier ice. Already, the average global mean sea level is rising at about 10–20 cm per century. Further global warming could cause it to rise an additional 20 cm by 2030 and 65 cm by 2100, although with significant regional variation (Intergovernmental Panel on Climate Change 1990).

Such a rise in sea level would increase flooding in low-lying areas — for example, Charlottetown, Prince Edward Island (Timmerman and Grima 1988). Coastal erosion would increase — the rate of shoreline recession could be as much as 5 m per year in some areas of eastern Canada (Yuen 1990). A report outlining the possible effects of sea-level rise on the city of Saint John, New Brunswick, predicts flooding risks to residential neighbourhoods and inundation of lagoons for treatment of sewage and industrial wastes (Martec Ltd. 1987). The economic and ecological effects of such flooding could be enormous. However, given the shortcomings of present-day global climate models, it is difficult to predict the magnitude of any impacts (see Chapter 22).

In the Arctic, sea-level rise would affect lowland areas such as the Mackenzie delta. Higher temperatures are expected to increase permafrost melting (Lester and Myers 1989). This melting would undoubtedly create depressions and flooding along the arctic coast, with impacts on the habitat of shorebirds, waterfowl, and other wildlife. Harington (1986) suggested that with a temperature rise, fish and harp seal numbers would increase, whereas walruses and bowhead whales would expand their range northwards. Ringed seals and bearded seals would shift northwards as well, with an expansion in numbers and range. Effects on river flows and ice cover are particularly difficult to predict. Because of the magnitude of potential climatic changes in the Arctic, further research and monitoring are especially important.

Ozone depletion

The ozone layer in the upper atmosphere (lying between 15 and 35 km above the Earth's surface) is a natural filter, shielding the Earth against the sun's damaging ultraviolet rays. Scientists are concerned about observed changes in the ozone layer, particularly in the last decade. The discovery of a "hole" in the ozone layer over Antarctica focused attention on issues related to increased amounts of ultraviolet radiation, which causes skin cancer, reduces crop yields, and causes damage to aquatic life (see Chapter 23). In the marine environment, increases in ultraviolet radiation may have adverse effects on groups of marine organisms such as marine microbes, phytoplankton, and zooplankton, especially at the sea surface. The implications are profound, for these organisms are the very foundation of marine food chains and thus support marine ecosystems and commercially important fisheries. However, knowledge of the impacts of ozone depletion on the marine ecosystem is very limited, and further research is required.

THE MANAGEMENT RESPONSE: HEEDING THE SEA'S CRY

The last three decades have witnessed a remarkable shift in public perception: where formerly the oceans were perceived as frontiers to be conquered or exploited or as convenient dumping grounds, today the need to protect the marine environment has become a global priority. For example, the protection of the marine environment, including enhancing the so-called United Nations Environment Programme Montreal Guidelines, completed in Montreal in 1985 to control land-based sources of marine pollution, will be a key agenda item at the upcoming United Nations Conference on Environment and Development in 1992.

The Montreal Guidelines were the first attempt by the international community to deal specifically and comprehensively with this subject at the global level. The guidelines present a checklist of scientific and managerial principles and strategies from which governments can select measures appropriate to the needs of their regions. Also, they are designed to assist countries in developing appropriate bilateral, regional, and multilateral agreements and national legislation for the control of land-based pollution — the source of 80% of the oceans' pollutants. Their strengthening and implementation through a commonly agreed-upon instrument such as a convention or agreement are important and urgent challenges for all coastal nations.

Canada is one member in a rapidly changing global community. Industrial expansion with an emphasis on high technology is sweeping many countries. This trend is driven by increased economic competition in the global marketplace. Industrialization on both coasts of Canada is changing the pressures that industrial activities exert on the marine environment. Recently, for example, it has been necessary to control the release of base metals and synthetic organic compounds produced by new and sophisticated industrial techniques.

Efforts within Canada to protect marine resources and marine environmental quality are reflected in numerous policies, laws and regulations, and strategic plans. In addition, assessment and monitoring programs are making it possible for managers to identify priorities, assess trends in marine environmental quality, and evaluate the effectiveness of measures taken to prevent or control damage. This section reviews some current attempts to strengthen Canada's capacity to manage human activities that influence the health of marine ecosystems.

Policy initiatives

Federal departments and agencies that have responsibility for managing ocean resources, conducting marine scientific research, and protecting marine environmental quality include Energy, Mines and Resources Canada, Transport Canada, the Natural Sciences and Engineering Research Council of Canada, the Department of Fisheries and Oceans, and Environment Canada. Recent policies of the last two agencies indicate a growing consensus about the need to cooperate to minimize conflicts arising from human uses of marine waters, to enhance human benefits from use of ocean resources, and to protect marine environmental quality (Table 4.8).

Legislation

There is a wide array of federal and provincial legislation directly or indirectly related to Canada's oceans. Examples of federal acts include CEPA, the *Fisheries Act*, the *Arctic Waters Pollution Prevention Act*, and the *Canada Shipping Act*. Recent and proposed legislation addresses the need for improved coordination between institutions and enforcement of regulations to protect Canada's oceans and coastlines. Two initiatives may be particularly significant:

- There have been numerous developments in the Law of the Sea over recent years. Furthermore, the public is becoming increasingly concerned that development of all resources, including ocean resources, be environmentally sustainable. The goal of the proposed Canada Oceans Act would be to provide an environmentally sustainable foundation for the development of Canada's ocean resources taking into account recent developments in international law.
- CEPA is aimed at protecting both the environment and human health from the risks of toxic substances. Under CEPA, the government sets environmental quality objectives and develops codes of practice for handling toxic chemicals. Corporate officials can be punished with fines of up to $1 million per day if they authorize or participate in activities that violate the act. As a comprehensive act, CEPA will play a key role in protecting Canada's ocean resources from chemical contamination.

TABLE 4.8

Initiatives for managing ocean resources and protecting the quality of the marine environment

Arctic Marine Conservation Strategy	The Department of Fisheries and Oceans is working with other federal agencies, provincial and territorial governments, native organizations, and northern communities to develop and implement an Arctic Marine Conservation Strategy. The strategy will recognize the uniqueness of the Canadian Arctic and the need to manage arctic resources through consensus. The strategy involves shared responsibility for resource management, based on sound scientific information, research, environmental protection, public education, and international cooperation.
Fish Habitat Management Policy	This Department of Fisheries and Oceans policy is guided by a principle of "no net loss" of the productive capacity of habitats and relies on cooperative, integrated resource planning for habitat management.
Policy for Recreational Fisheries	This policy of the Department of Fisheries and Oceans is based on a cooperative management approach, whereby governments and resource users share responsibility for conservation and wise use. Policy goals include the following: (i) to conserve, restore, and enhance Canada's recreational fisheries and the habitat on which they depend; (ii) to maintain a high quality and diversity of recreational fishing opportunities; and (iii) to encourage a viable recreational fishing industry.
Marine Parks Policy	Initiated under the Canadian Parks Service of Environment Canada, the policy is an important vehicle for conserving marine ecosystems. The policy recognizes that the nature of marine parks is different from that of terrestrial parks and acknowledges the need to accommodate different resource uses. Canada's oceanic and Great Lakes areas are divided into 29 natural areas, and the long-term goal is to create a national network in which each of these 29 regions is represented.
Oceans Policy	Announced in 1987, this policy provides a broad strategy for maximizing the economic, scientific, and sovereignty benefits from Canada's oceans. A key goal of the Oceans Policy is to ensure that ocean resources and the ocean environment are soundly managed and protected for future generations.
Marine Environmental Quality Framework	The framework is a national initiative to protect the marine environment. The framework recognizes that government, industry, and the public have roles to play and emphasizes the need for coordinated action. Planning will focus on specific actions in several key areas, including monitoring, development of guidelines, environmental reporting, integrated coastal management, marine environmental research, and compliance and enforcement.
Cultivating the Future	To help the aquaculture industry to become a leading world producer by the turn of the century, this policy developed by the Department of Fisheries and Oceans sets five goals: (i) support for the industry through scientific and technical leadership and innovation; (ii) sound cooperative management for a healthy and productive aquatic environment; (iii) an inspection system to support the industry's reputation for high-quality products; (iv) provision of market analysis and advice; and (v) advocacy and dialogue to promote sustained growth in the industry.
Canada's Green Plan	Canada's Green Plan (Government of Canada 1990*a*) contains more than 100 initiatives to be implemented over the next six years at a total cost of $3 billion. A large number of these initiatives bear directly or indirectly on the quality of the marine environment. Key programs include the Arctic Environmental Strategy, the Fraser River Basin Action Plan, restoration of Atlantic hot spots, the Ocean Dumping Action Plan, improved understanding of toxic substances, sustainable fisheries development, a regulatory action plan for toxic chemicals, improved water science and technology, new biotechnology standards, more effective stewardship of coastal and marine waters, cleaning up contaminated sites, improved understanding of global warming, the proposed Canadian Environmental Assessment Act, enhanced state of the environment reporting and environmental information, preventing and responding to marine spills, and strengthening of environmental partnerships, among others.

Strategic planning

The purpose of strategic planning is to translate policies and legislation into action. Area-specific environmental action plans have been initiated to address special problems in marine and freshwater environments. In June 1988, the government launched a five-year, $110-million program to restore and conserve the quality of the St. Lawrence River and estuary and their resources through reduction of contaminant discharges from 50 targeted industries and through research and rehabilitation (see Chapter 19). The St. Lawrence River Action Plan also includes the creation of a marine park at the confluence of the St. Lawrence and Saguenay rivers (see Box 4.2), an effort linked to saving the endangered St. Lawrence beluga population. Green Plan funding to develop remedial action plans for at least 11 harbours and coastal areas in the Maritimes was announced in March 1991. The 11 initial sites to be targeted include Saint John Harbour and the Letang Inlet, New Brunswick, Sydney Harbour, Nova Scotia, and St. John's Harbour, Newfoundland. An action plan for cleanup and management of British Columbia's Fraser River and Burrard Inlet as identified under the Green Plan (Government of Canada 1990*a*) was also announced in June 1991. Other federal and provincial strategic plans, including a plan to establish a national network of marine protected areas and integrated resource management plans for coastal (or shore) zones, are at various stages of development.

Marine protected areas

Protection of marine ecosystems lags far behind protection of terrestrial areas, although British Columbia founded a system of marine parks in 1959, primarily to protect seabird colonies. Nationally, of the 29 marine regions identified by the Canadian Parks Service, five cover the Great Lakes and the remainder Canada's three oceans. Two of the regions are represented in established parks: Georgian Bay, and a portion of the continental shelf off the west coast of Vancouver Island. The federal government, through the Green Plan (Government of Canada 1990*a*), is committed to establishing three more national marine parks by 1996, including South Moresby/Gwaii Haanas and

Saguenay, and an additional three by the year 2000 (see also Chapter 7). The Marine Parks Policy, released in 1986, set an overall target of 29 marine parks, one for each distinctive natural marine region in Canada.

BOX 4.2

The creation of Saguenay Marine Park

Where the Saguenay and St. Lawrence rivers meet, turbid waters from the upper St. Lawrence estuary and warmer Saguenay surface waters mix with the colder marine waters from the Gulf of St. Lawrence, creating special environmental conditions that attract a remarkable number of whale species for such a small area. Minke, blue, beluga, and fin whales feed in the cold, rich waters of the lower estuary, and sea anemones, whelks, crabs, and many other diverse species carpet the seafloor. At the mouth of the Saguenay River, the less saline water floats on top of the cold salt water, so, in effect, there are two very different marine communities superimposed one on top of the other.

It is hardly surprising that this distinct marine region was chosen as one of Canada's six new marine parks slated for development, under the Green Plan, for the year 2000. Creating marine parks raises public awareness of our natural marine heritage and reserves an area for marine recreation and research. The Saguenay Marine Park's specific advantages are that it provides a sanctuary for the endangered beluga, the southernmost population of belugas in the world, and it draws attention to the considerable pollution from diverse sources upstream.

The geographic and oceanographic features of the area also contribute to the uniqueness of the region. For more than one-half its length, the Saguenay River is actually a fjord connected to the St. Lawrence estuary. The proposed site of the Saguenay Marine Park includes the Saguenay River downstream of Cap à l'Est and the northern fringe of the St. Lawrence where it meets the Saguenay (Fig. 4.B2). It is also surrounded by a terrestrial park. The park's proposed boundaries are being reviewed by the federal and Quebec governments, as well as through public hearings.

Although the park is being set up with the primary objective of restoration of environmental quality, it is still recognized that improvement in water quality will require strong cooperative efforts by a variety of agencies (see Chapter 19). As part of the conservation strategy for the park, access to sensitive areas, such as beluga habitats, will be restricted. Activities such as sailing, sea kayaking, canoeing, windsurfing, recreational fishing, scuba diving, and whale watching will continue, but in a manner that does not compromise the protection of the park's many unique features. Visitor centres, information, and interpretation will be made available. The park will also publish an annual report on the scientific research taking place.

The federal and Quebec governments will be working together in the establishment and management of the park, and a management plan is scheduled for release in summer 1993. This joint initiative will help ensure that one of Canada's unique marine areas is conserved for future generations of Canadians.

Coastal zone management

The purpose of sustainable coastal management is to encourage well-planned economic development that includes environmental protection and conservation. To date, the Canadian approach to managing coastal pressures has been largely uncoordinated as a result of fragmented jurisdictional responsibility for marine and coastal resources (Hildebrand 1989). Partly as a result, few coastal management plans have been developed despite Canada's huge coastline and its many valuable coastal resources.

Recent initiatives on all three coasts indicate that there is growing awareness of the need for some form of area-wide management if resource conflicts are to be minimized and special areas protected. For example, in British Columbia, three estuarine management plans have been developed (Cowichan, Squamish, and Fraser rivers). In the Atlantic, Prince Edward Island has prepared a comprehensive coastal inventory to assist shellfish growers in site selection. In 1988, the Atlantic Estuary Co-operative Ventures project was initiated by Environment Canada, Atlantic Region. Federal and provincial governments, universities, and local authorities are participating in plans for managing four estuaries, one in each Atlantic province. A further example of cooperative resource management planning is the Gulf of Maine Action Plan, which involves two provinces and three states, with U.S. and Canadian federal government participation.

Northern land-use planning, which began when concerns about conflicts between industrial development and traditional resource use intensified, is winding down. The federal–territorial Northwest Territories Land Use Planning Commission was created in 1986 but was dissolved in 1988 and replaced by three regional commissions, two of which include coastlines — Lancaster Sound and Beaufort Sea–Mackenzie delta, both in the Northwest Territories (see Chapter 15).

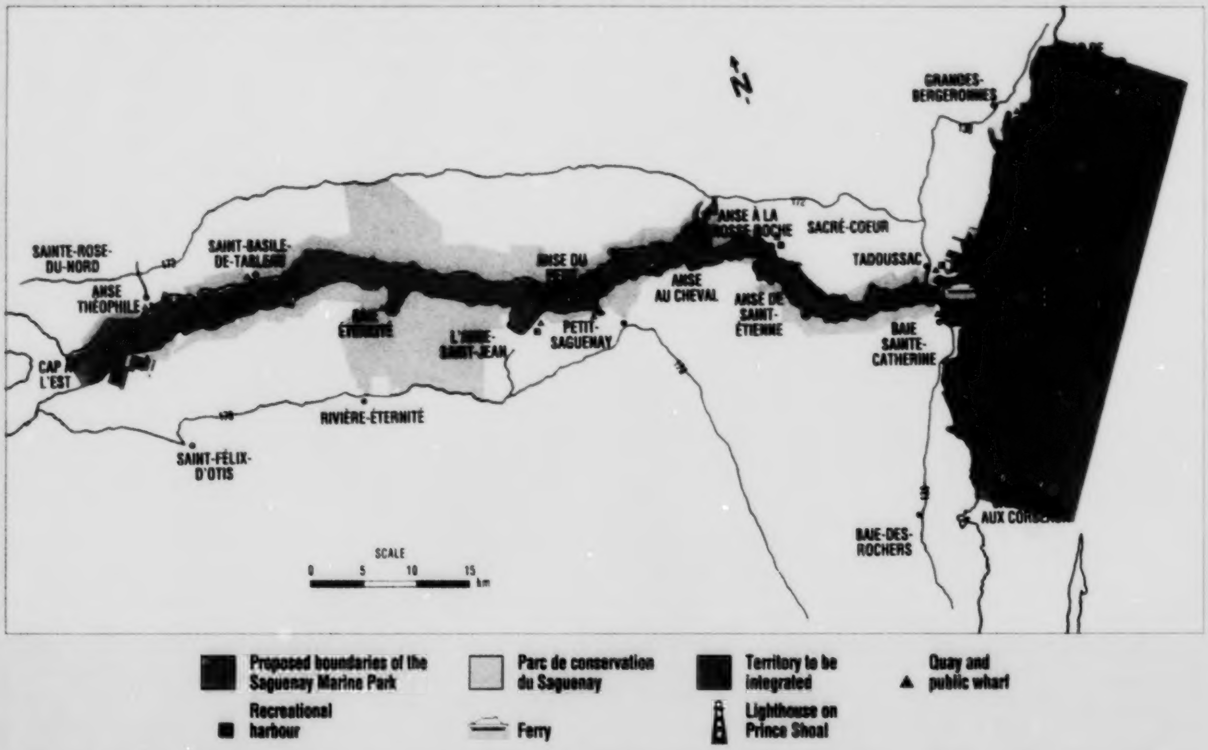
Monitoring programs

Monitoring is used to assess the need for, and effectiveness of, measures to prevent pollution. Existing programs track contaminant levels in river waters, in the atmosphere, and in seabird eggs and monitor the quality of shellfish habitat and the effects of coastal pulp mills and other pollution sources. These programs are providing valuable information; however, more is needed, particularly concerning the distribution and fate of contaminants and their effects on marine biota and habitats. Efforts to establish additional monitoring programs are under way on Canada's three coasts.

The Green Plan (Government of Canada 1990*a*) identifies oceans-related priority issues. In these areas,

FIGURE 4.82

Saguenay Marine Park: proposed boundaries


N
GRANDES-BERGERONNES
SAINTE-ROSE-DU-NORD
SAINT-BASILE-DE-TABLEAU
ANSE THÉOPHILE
CAP À L'EST
BAIE ÉTERNITÉ
L'ANSE-SAINT-JEAN
ANSE DU
PETIT-SAGUENAY
ANSE À LA ROCHE
SACRÉ-COEUR
ANSE AU CHEVAL
ANSE DE SAINT-ÉTIENNE
TADOUSSAC
BAIE SAINTE-CATHERINE
RIVIÈRE-ÉTERNITÉ
SAINT-FÉLIX-D'OTIS
BAIE-DES-ROCHERS
AUX CORBEAUX
172
170
138
SCALE
0
5
10
15
km
Proposed boundaries of the Saguenay Marine Park
Parc de conservation du Saguenay
Territory to be integrated
Quay and public wharf
Recreational harbour
Ferry
Lighthouse on Prince Shoal

Source: Environment Canada (1990*b*).

monitoring and assessment will increase and actions will be taken to facilitate the exchange of information among the diverse authorities responsible for effects on the marine environment, oceanic and coastal resources, and human health. Some examples are as follows:

- contaminant levels in, and the state of, fish stocks in major recreational and subsistence fisheries;
- toxic substances and their effects on fish and fish habitat;
- high-seas drift-net operations;
- northern water quality;
- climatic change and climate-related ocean research.

CONCLUSIONS

There are many inshore areas and estuaries on Canada's three coasts that exhibit evidence of environmental degradation, in some cases severe, with significant risk to living resources, habitats, and occasionally public health. Human influence on the marine environment is evident in many areas. Direct inputs of sewage, industrial wastes, and agricultural chemicals have led to bacterial contamination, eutrophication, habitat loss or degradation, and toxic effects on marine flora and fauna. Shipping and oil and gas development further threaten environmental quality. To varying degrees, these stresses afflict each of Canada's three oceans, extending even to remote arctic waters. In short, there are sufficient early-warning signals to suggest that Canada could be heading in the direction of other, more populated, industrialized nations that are pushing their resources to the limit and suffering the consequences of marine degradation (Environment Canada 1989).

In the Atlantic, fishing has seriously depleted groundfish stocks, resulting in closures of fish plants and economic hardship in coastal communities that, in some instances, have been dependent on the fishery for more than three centuries. Municipal and industrial effluents have contaminated traditional shellfish harvesting areas and limited the expansion of aquaculture. Aluminum smelters and pulp mills on the Saguenay River continue to add to the toxic contaminant load of sediments and, ultimately, of endemic species such as the endangered St. Lawrence beluga.

Many of these same problems — overfishing and municipal and industrial contamination — are mirrored on Canada's west coast. Of particular concern is the practice of high-seas drift-net fishing by Pacific nations, which constitutes a major threat to marine mammals, seabirds, and nontarget fish species, such as salmon. Urban growth, concentrated in the coastal communities of Vancouver, Victoria, and Nanaimo, continues to contaminate nearshore habitat and to consume productive wetlands. An acute concern on the west coast is the loss of the commercial and recreational fisheries for crabs, prawns, shrimp, and oysters near pulp and paper mills, which are sources of chlorinated organic compounds, including dioxins and furans.

Although the Arctic Ocean is relatively unpolluted, compared with Canada's more southerly seas, increasing pressure to develop both renewable and nonrenewable resources may lead to deteriorating environmental quality. A potential threat to the health of the subarctic coastal ecosystems is hydroelectric development at La Grande River, as well as proposed projects on the Great Whale, Nottaway, Broadback, and Rupert rivers in northern Quebec, on the Moose River in Ontario, and on the Nelson River in Manitoba (see Chapter 12). A particularly distressing finding, in recent years, is that chlorinated organics are widespread in the arctic food chain.

Impacts on the marine environment have, in many instances, had economic consequences in areas such as shellfish harvesting and tourism. Having recognized this, Canadians are responding. Environmental controls have reduced a number of threats. Some of the more persistent pesticides are no longer in use, and there are codes of practice for handling other toxic materials under CEPA. New regulations under the *Fisheries Act* and CEPA to set and control industrial effluent discharging practices are components of Canada's Green Plan (Government of Canada 1990*a*). Without such measures, habitat loss, ecosystem degradation, and fishery closures would likely be more widespread.

Canada needs a comprehensive set of environmental objectives that define acceptable levels of marine environmental quality, as well as enough baseline information to evaluate the condition of the environment against these standards. This will require increased research into the fates of toxic contaminants in marine ecosystems and the effects of these and other stresses on marine environmental quality. The design and implementation of environmental monitoring programs to provide information on trends in marine environmental quality are also critical, both as an early-warning system for emerging problems and as feedback on the effectiveness of regulatory and management initiatives.

The limits to our current knowledge, however, do not preclude positive action. In many cases, existing Canadian control measures are not enforced uniformly on all three coasts. This can be corrected. Reducing consumption of fossil fuels, implementing more stringent controls on industrial pollution, enhancing enforcement capability, and devising better strategies for managing and treating wastes are a few steps that can be taken immediately to protect Canada's oceans and coastlines from the effects of increasing urbanization and industrialization. Everyone has a role to play in heeding the sea's cry and helping to sustain Canada's seas for the future.

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5

COURTESY OF E.W. MANNING OTTAWA

HIGHLIGHTS

Canadians perceive and value the land in very different, often incompatible, ways — some view land as an indivisible part of life-sustaining ecosystems, others as a commodity to be bought and sold. These fundamental differences in viewpoint often lead to land-use conflicts.

■

An estimated 65% of Atlantic coastal marshes, 70% of the wetlands of southern Ontario and the Prairies, and 80% of the wetlands of the Fraser River delta in British Columbia have been drained, mainly for agricultural use.

■

From 1981 to 1986, the Toronto urban-centred region absorbed 100 km^2 of prime agricultural land; Edmonton, 40 km^2; Montreal, approximately 6 km^2; and Vancouver, 6 km^2. The so-called urban shadow, outside the city core, has far-reaching economic and social effects, generally making rural life less viable.

■

Many sites throughout Canada have been contaminated by careless disposal of wastes or accidental spills. This is true even in the remoteness of Canada's Arctic, where soils around some abandoned and active military sites are contaminated with PCB wastes, with unknown consequences for the arctic food chain.

■

Land is a prime resource whose management is complicated by shared jurisdiction. Governments at all levels are attempting to develop legislation and policies to encourage and protect sustainable use of the land.

■

Canada has committed itself to setting aside 12% of its territory for protection of representative ecosystems, as outlined in the Green Plan.

■

Currently, aboriginal peoples are involved in 606 specific land claims regarding the administration of land and other assets and the fulfilment of obligations arising from treaties, the *Indian Act*, and other federal legislation.

■

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> **Societies need a direct link with the earth. Our ancestors were first hunter-gatherers, then farmers and city dwellers. We still need contact with the soil. Our collective unconscious includes someone who works with the land to produce food. Each of us also wants to know that the land — his land, her land — is not being abused. Our kinship with the land sometimes is dormant while we run on urban treadmills trying to achieve nebulous goals: but it is there and it is important.**
>
> — Jerome Martin (1991)

INTRODUCTION

"Land" — the word has a variety of connotations. It signifies solid ground or terra firma, the physical environment at large, a rural farmstead, an urban industrial site, and private property; it also holds deep, personal meaning for some people. This diverse association of ideas about land shows the extent to which the concept is interwoven with culture and points to differences in the ways in which land is perceived and valued in Canadian society, differences that in turn give rise to some very difficult land-use issues.

Before European explorers and settlers came to what is now Canada, human activities had impinged little upon the land. The native Indian and Inuit peoples lived mainly by hunting, fishing, and gathering — an economy and way of life that, compared with modern-day culture, had only minor effects on the land base. Some had permanent settlements, but these were not major intrusions on the natural landscape. The aboriginal peoples' attitudes towards the land were spiritually based as well as ecologically sound. They saw the land and the living things it supported — including humans — as indivisible.

European settlers introduced a new concept of land. Coming from societies based on permanent agricultural and urban communities, the newcomers brought with them a more human-centred, utilitarian view of the land — it was the medium through which they supported themselves, by felling its trees for fuel and lumber, cultivating it for food, and building permanent settlements on it. They also brought with them the view of land as personal property. This concept of land "ownership" originated in a settled, agrarian society with a need to designate particular tracts for the exclusive use of individuals or families. Unfortunately, property boundaries often bore little relationship to the natural form or characteristics of the land itself.

With the demands of a modern industrial economy came a further evolution in the perception of land. As settlements expanded and as competition among land uses intensified, land came to be viewed mainly as a commodity, to be bought and sold and speculated upon according to the demands of the marketplace. Many of the activities of modern men and women — mechanical resource extraction, industrial development, and urban settlement — have resulted in the degradation of the soil. The upper 2.5 cm of this fragile, finite legacy — the thickness of a pocket novel — required 300–1 200 years to accumulate.

Public perception of land does not extend to viewing it as a resource to be protected, in the same sense that air and water are so regarded. People see land as something from which resources come, not as a resource itself. In general, land issues are not addressed in a coordinated fashion. They are singled out, not integrated — as when problems with garbage dumps are looked at solely as waste disposal problems, not as land-use problems as well.

THE NATURE OF CANADA'S LAND BASE

In a physical sense, land is defined as the predominantly solid layer of the Earth's surface that interacts continuously with the atmosphere, surface water, and terrestrial lifeforms. In a global context, Canada's dominant characteristic is its abundance of land. Its borders are roughly 5 300 km from coast to coast, "as the crow flies," from St. John's, Newfoundland, to the Queen Charlotte Islands in British Columbia, and nearly 4 600 km from Point Pelee in southern Ontario to Alert on Ellesmere Island in the high Arctic. Canada's land mass of approximately 9 215 000 km^2 is second in size only to that of the Soviet Union — 22 400 000 km^2. In comparison, the United States and Australia have land areas of 9 167 000 km^2 and 7 818 000 km^2, respectively (Organisation for Economic Co-operation and Development 1989).

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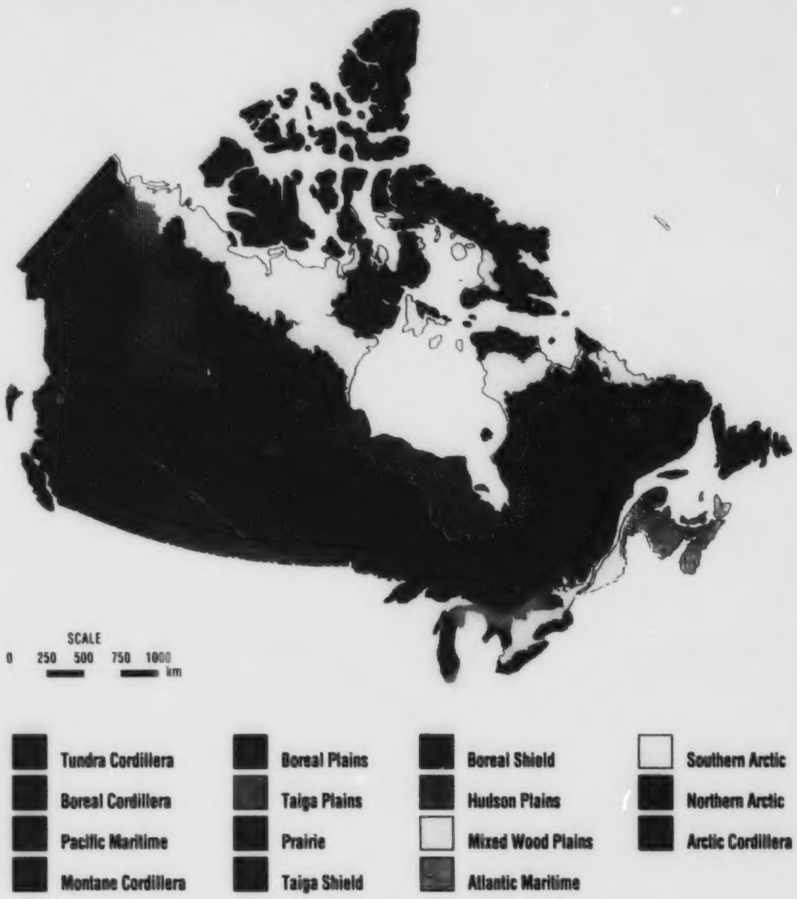
The terrestrial ecozones of Canada



Source: Environment Canada, State of the Environment Reporting, 1986.

A diverse range of landforms, bedrock, surface materials, soils, and vegetation form Canada's geography. To assist in the appreciation of this wealth of physical and biological features, and to facilitate a better understanding of their interrelationships, the land can be categorized in various ways based on similarities of such features. Figure 5.1 illustrates one such categorization — terrestrial ecozones, which are areas of the Earth's surface representative of ecological units. Table 5.1 briefly describes some of the physical, biological, and land-use characteristics associated with each of these ecozones.

Land covers are another such categorization. As might be expected, given its vastness and variability of climate to match its size, Canada exhibits a variety of land covers, from crops to permanent ice. Figure 5.2 illustrates the primary land cover classes, as derived from LANDSAT satellite imagery and aerial photography. Table 5.2 indicates the predominant cover for each land class, as well as the area and percentage of Canada represented by each class.

MAJOR LAND USES

The diversity of landscape that Canada enjoys has led to varied uses of the land base. Table 5.3 shows the predominant land activities in Canada and the area and percentage of the country represented by each activity class.

Human uses of the land and its resources laid the foundation of the contemporary Canadian economy and turned Canada into one of the principal suppliers of raw materials and food to world markets. The forests of southern Ontario and Quebec were cleared for agricultural crops, and the evergreen forests farther north were harvested to supply timber for shipbuilding, construction, railway ties, and, later, pulp for the manufacture of paper. In the early 1900s, the prairie grasslands were transformed into cultivated crops and farm units. More recently, dams have flooded large tracts of land to generate hydroelectricity, particularly in northern Quebec and British Columbia. Oil and gas wells have been drilled throughout the sedimentary basins of the western provinces. These widespread activities have altered not only the land but also our perception that, in Canada, land resources are virtually infinite.

The principal land-use sectors — forestry, agriculture, mining and energy, transportation, and urban settlement — and some of the land-use issues arising from these activities are discussed in greater detail below.

Forestry

The longest-lasting and most negative stress on forest land is the lack of regeneration of a commercially viable forest on cutover lands (Simpson-Lewis *et al.* 1983). Currently, 89.6% of logging in Canada is carried out by clear-cutting. In addition, of the 10 000 km^2 of forest harvested in 1988, only 8 230 km^2 were regenerated (Forestry Canada 1991), leaving approximately 18% unreforested.

Agriculture

Despite Canada's immense size, only about 5% of its total area is capable of supporting a variety of crops — an area approximately the size of the four Atlantic provinces. Much of this very limited prime land base is being modi-

TABLE 5.1

Some physical, biological, and land-use characteristics of the terrestrial ecozones of Canada

No.	Ecozone	Landforms	Soils; surface materials	Climate	Vegetation	Wildlife (mammals; birds)	Land use	Communities
1.	Tundra Cordillera	Mountains	Cryosols, Brunisols; colluvium, moraine, rock	Cold, semiarid	Shrub–herb–moss–lichen tundra	Dall's sheep, Grant's caribou, black bear, grizzly bear; Peregrine Falcon, ptarmigan	Trapping, hunting, mining, tourism/recreation, oil and gas	Old Crow
2.	Boreal Cordillera	Mountains, some hills, plains	Brunisols, Cryosols; colluvium, moraine, rock	Moderately cold, moist	Mixed evergreen–deciduous forest; some tundra, open woodland	Moose, Dall's sheep, grizzly bear, black bear; ptarmigan, Spruce Grouse	Hunting, trapping, forestry, tourism/recreation, mining	Whitehorse, Dawson, Faro, Teslin, Haines Junction, Mayo Landing
3.	Pacific Maritime	Mountains; some coastal plains	Podzols, Brunisols; colluvium, moraine, rock	Mild, temperate, very wet	Coastal evergreen forest	Black bear, grizzly bear, mountain lion; American Black Oystercatcher, Tufted Puffin	Forestry, fish processing, urbanization, agriculture	Vancouver, Victoria, Prince Rupert, Nanaimo, Port Alberni, Chilliwack
4.	Montane Cordillera	Mountains and interior plains	Luvisols, Brunisols; moraine, colluvium, rock	Moderately cold, moist to arid	Evergreen forest, alpine tundra, interior grassland	Woodland caribou, mule deer, moose, wapiti, mountain goat; Blue Grouse, Steller's Jay	Forestry, agriculture, tourism/recreation	Prince George, Kelowna, Kamloops, Williams Lake, Vernon, Penticton, Nelson, Trail, Cranbrook, Quesnel
5.	Boreal Plains	Plains; some foothills	Luvisols; moraine, lacustrine	Cold, moist	Mixed evergreen–deciduous forest	Woodland caribou, mule deer, moose, black bear, beaver, muskrat; Boreal Owl, Blue Jay	Forestry, agriculture, tourism/recreation, oil and gas development, marginal agriculture in south	La Ronge, The Pas, Flin Flon, Peace River, Fort Vermilion, Hinton
6.	Taiga Plains	Plains; some foothills	Cryosols, Brunisols; organic, moraine, lacustrine	Cold, semiarid to moist	Open to closed mixed evergreen–deciduous forest	Moose, woodland caribou, wood bison, wolf, black bear, red squirrel; Northern Shrike, Spruce Grouse	Hunting, trapping, tourism/recreation, oil and gas development, marginal agriculture in south	Inuvik, Fort Simpson, Wrigley, Norman Wells, Aklavik, Hay River, Fort McPherson, Pine Point, Fort Smith
7.	Prairie	Plains; some foothills	Chernozems; moraine, lacustrine	Cold, semiarid	Grass; scattered deciduous forest ("aspen parkland")	Mule deer, white-tailed deer, pronghorn, coyote, prairie dog; Sage Grouse, Burrowing Owl	Agriculture, urbanization, recreation, oil and gas development	Calgary, Winnipeg, Edmonton, Regina, Saskatoon, Lethbridge, Red Deer, Prince Albert, Brandon
8.	Taiga Shield	Plains; some interior hills	Cryosols, Brunisols; moraine, rock	Cold, moist to semiarid	Open evergreen–deciduous trees; some lichen–shrub tundra	Moose, barren-ground caribou, wolf, snowshoe hare, red squirrel; Red-necked Phalarope, Northern Shrike	Tourism/recreation, some mining, some hunting and trapping	Yellowknife, Goose Bay, Uranium City, Churchill Falls, Labrador City, Kuujjuarapik
9.	Boreal Shield	Plains; some interior hills	Podzols, Brunisols; moraine, rock, lacustrine	Cold, moist	Evergreen forest, mixed evergreen–deciduous forest	White-tailed deer, moose, black bear, lynx, marten, red squirrel; Boreal Owl, Blue Jay	Forestry, mining, tourism/recreation, hunting, trapping	Thunder Bay, St. John's, Sudbury, Sault Ste. Marie, Chicoutimi, North Bay, Sept-Iles, Gander
10.	Hudson Plains	Plains	Cryosols; organic, marine	Cold to mild, semiarid	Wetland; some herb–moss–lichen tundra, evergreen forest	Woodland caribou, moose, black bear, marten, arctic fox; Canada Goose	Hunting, trapping, recreation	Churchill, Moosonee, Attawapiskat
11.	Mixed Wood Plains	Plains; some interior hills	Luvisols; moraine, marine, rock	Cool to mild, moist	Mixed deciduous–evergreen forest	White-tailed deer, red fox, raccoon, striped skunk, beaver, grey squirrel; Great Blue Heron, Blue Jay	Agriculture, urbanization, tourism/recreation	Toronto, Montreal, Windsor, Hamilton, Quebec, Ottawa, London, Mississauga, Sherbrooke
12.	Atlantic Maritime	Hills and coastal plains	Brunisols, Luvisols; moraine, colluvium, marine	Cool, wet	Mixed deciduous–evergreen forest	White-tailed deer, moose, black bear, coyote, raccoon; Blue Jay, Eastern Bluebird	Forestry, agriculture, fish processing, tourism/recreation	Halifax, Saint John, Dartmouth, Charlottetown, Moncton, Sydney, Rimouski
13.	Southern Arctic	Plains; some interior hills	Cryosols; moraine, rock, marine	Cold, dry	Shrub–herb tundra	Barren-ground caribou, wolf, grizzly bear, arctic fox, arctic ground squirrel, lemming; Arctic Loon, ptarmigan, Snowy Owl	Hunting, trapping, tourism/recreation	Tuktoyaktuk, Rankin Inlet, Arviat, Coral Harbour, Igloolik, Paulatuk
14.	Northern Arctic	Plains and hills	Cryosols; moraine, rock, marine	Very cold, dry	Herb–lichen tundra	Peary caribou, muskox, wolf, arctic hare; Red-throated Loon, Brant, ptarmigan, Greater Snow Goose	Hunting, tourism/recreation, some mining	Iqaluit, Cambridge Bay, Holman, Arctic Bay, Spence Bay, Pangnirtung, Sachs Harbour, Cape Dorset, Resolute
15.	Arctic Cordillera	Mountains	Cryosols; ice, snow, colluvium	Extremely cold, dry	Mainly unvegetated; some shrub–herb tundra	Polar bear (along coast), arctic hare; Northern Fulmar, Common Ringed Plover, Snow Bunting	Hunting	Pond Inlet, Clyde River, Broughton Island

Source: Wiken (1986).

fied. Although the total land area in farm use in Canada has remained almost unchanged in recent years, the quality of land in production has declined. Much of the highly productive land for agriculture has been converted to urban uses. It is ironic that, in many instances, the land that has been converted to urban uses was suitable for the widest range of crops, whereas the land that has been brought into agriculture, mainly in northern portions of the Prairie provinces (see Fig. 5B.1, Box 5.1) and British Columbia, is of much lower productivity and suitable for a reduced range of crops. This net reduction in quality of farmland has been only somewhat offset by a trend towards more intensive production of higher-value crops.

Like forestry, agriculture has become increasingly mechanized, resulting in more intensive use of the land resources. These pressures are manifested, both on the farm and in the surrounding environment, in many direct, and more subtle, ways: water and wind erosion, soil and water contamination due to high use of pesticides and fertilizers, and cultivation of marginal lands at the expense of the land's other resource values for forestry, wildlife, or recreation.

In addition to domestic pressures, there are also major external influences — such as international competitive trends and long-term global climatic change — that will affect agricultural use of land in Canada.

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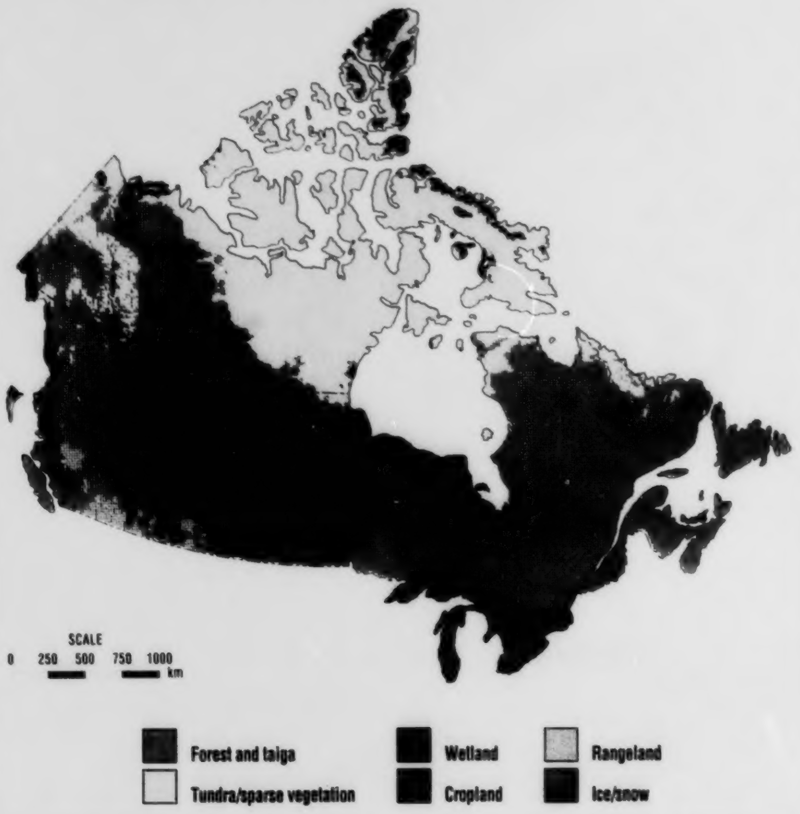
Primary land cover in Canada by ecodistrict, 1985



Source: Rubec (1989).

Mining and energy

Although, on a national scale, mining and energy are not major land users, they nonetheless play a major role in Canada's economy and are geographically widespread. Mining makes direct use of less than 0.03% of Canada's land area. More than half of this is composed of pits and quarries for the extraction of construction aggregates, such as sand, gravel, and crushed rock (Marshall 1982). An oil or gas drill site typically occupies only about 0.015 km^2, excluding storage areas. Despite these seemingly insignificant figures, mining and energy industries can have considerable impacts upon the land resource (see Chapters 11 and 12). Arctic landscapes are particularly susceptible to damage and slow to recover from even minor disturbances related to oil and gas exploration or development (see Chapter 15). The disposal of mine tailings and other industrial wastes often requires much greater areas of land than are occupied by the mine sites themselves. Sand and gravel pits tend to be located close to settled areas. Extraction of aggregates can destroy prime croplands or grazing lands and decrease significantly the scenic quality of landscapes.

Dams and reservoirs for hydroelectric energy production and other uses are increasingly significant land users. For example, the La Grande power project in the James Bay area of northern Quebec, begun in 1972, has flooded a total of 10 000 km^2 of land (approximately the size of Cape Breton Island), including many traditional Cree trap lines, and this could be increased substantially by the second and third phases of the northern Quebec developments. Although most hydro development projects are of a much smaller scale, they can, nevertheless, have significant effects. In British Columbia, for example, there are concerns that the proposed Site C project on the Peace River southwest of Fort St. John would decrease significant wildlife habitat and lands with high agricultural capacity (Thompson 1990).

Transportation

Transportation networks of highways, railways, and airports perform a vital service; however, they produce a variety of adverse environmental and social effects. Highways often alter storm runoff, thus increasing erosion and damaging roadside vegetation. Railways, in decline in recent years despite positive virtues as a means of public conveyance, pose potentially adverse environmental effects of their own, often blocking wildlife corridors and alienating wildlife habitats.

Airports consume large areas of land that is often of prime agricultural value. For example, in 1969, the federal government expropriated 360 km² of land to build Mirabel International Airport, 60 km north of Montreal. More than 2 200 families, many resident on centuries-old farms, were dislocated, even though the construction of the airport required only 20 km², or about 5.6% of the expropriated land. Eventually, after 22 years, most of the expropriated land was sold back or leased to former residents, and the fertile fields have once again been returned to agricultural production (Picard 1991).

Although it is possible to identify potentially adverse environmental effects of transportation, it is more difficult to quantify and evaluate such effects and to incorporate them into land planning and management. Interrelationships among transport modes and among land uses served by them can make it difficult to isolate environmental impacts of transportation facilities. Secondary or indirect impacts are also difficult to assess. As examples of secondary impacts, urban development activities often follow the construction of a new or expanded airport, and a new highway may inadvertently increase access to a wilderness area.

[illegible]

Primary land cover in Canada

Land cover class	Predominant cover in the class	Area[a] (km², 000s)	% Canada total[b]
Forest and taiga	Closed canopy forest and/or open stands of trees with secondary occurrences of wetland, barren land, or others	4 456	45
Tundra/sparse vegetation	Well-vegetated to sparsely vegetated or barren land, mostly in arctic or alpine environments	2 303	23
Wetland	Treed and nontreed fens, bogs, swamps, marshes, shallow open water, and coastal and shore marshes	1 244	12
Fresh water	Lakes, rivers, streams, and reservoirs	755	8
Cropland	Fenced land (including cropland and pasture land), hedge rows, farms, and orchards	658	6
Rangeland	Generally nonfenced pasture land, grazing land; includes natural grassland that is not necessarily used for agriculture	203	2
Ice/snow	Permanent ice and snow fields (glaciers, ice caps)	272	3
Built-up	Urban and industrial land	79	1
Total		**9 970**	**100**

[a] Includes the area of all land and fresh water.

[b] Rounded to the nearest percent.

Note: Data for this table are derived from satellite imagery and may deviate slightly from other sources of data.

Source: Energy, Mines and Resources Canada (1989).

TABLE 5.3

Land activity in Canada

Land activity class	Predominant activity in the class	Area (km², 000s)[a]	% Canada total[b]
Forestry	Active forest harvesting or potential for future harvesting	2 440	24
Recreation and conservation	Recreation and conservation within national, provincial, and territorial parks, wildlife reserves, sanctuaries, etc.	708	7
Agriculture	Agriculture on improved farmland (cropland, improved pasture, summerfallow) and unimproved farmland	678	7
Urban/industrial	Residential and industrial activities of urban environments	72[c]	1
Other activities	Includes hunting and trapping, mining, energy developments, and transportation	6 072	61
Total		**9 970**	**100**

[a] Includes the area of all land and fresh water.

[b] Rounded to the nearest percent.

[c] Includes only the 25 major metropolitan areas.

Source: Environment Canada (1985).

Urban settlement

A simple statistical overview gives the impression that Canada is a big, empty country. Its average population density of 2.75 individuals per square kilometre (Statistics Canada 1990) is low indeed compared with that of Singapore (nearly 4 400 individuals per square kilometre) or the Netherlands (about 435 people per square kilometre) (World Resources Institute 1990). In Canada, however, the distribution of the population is more significant than the sheer numbers, as the majority of people live in the southern portions of the country where resources are generally more abundant and the climate is more favourable.

Urban development also plays a role in land degradation. The location of houses and other buildings in areas where there are physical hazards (e.g., on a floodplain, unstable slope, or eroding shoreline) can trigger or accelerate degradation processes, such as sheet erosion and slumpage. Site excavation and construction of buildings, roads, and pipelines, if inappropriately done,

BOX 5.1

Peace River, Alberta: Canada's agricultural frontier[1]

The Reverend J. Gough Brisk demonstrated the agricultural potential of the Peace River region of northwestern Alberta by winning the world wheat championship at the 1893 Chicago Exposition (Canadian Encyclopedia 1985). Thereafter, for most of the 1900s, the Alberta government encouraged agricultural development in the region by offering inexpensive or free "homestead" land, as well as by designating the region as outside the control of forest managers.

A century after Brisk's horticultural coup, the Peace River lowland, covering an area of approximately 45 000 km^2 (Fig. 5.B1), is Canada's fastest-advancing agricultural frontier. In 1961, 26.3% of the region had been converted to agricultural uses. By 1986, however, agriculture's share of the land base had jumped dramatically to 46.2%, leaving only slightly more than half of the land base in its naturally forested state (Table 5.B1).

During that 25-year period, approximately 360 km^2 or 20% of the forested land was cleared for agriculture — an annual rate of 0.81%. Although there is a vast difference in size of the area and complexity of ecosystems and environmental issues, this rate of deforestation is comparable with that of Amazonia between 1975 and 1988, when 0.87% of the forests were cleared annually (Mahar 1989).

To turn a phrase, not all land is created equal. In order for resource planners to select the best use for a given land base, they must first have a means of measuring what the land is capable of supporting, and how much of it there is in a given area. The Canada Land Inventory (CLI) system was developed for the purpose of assessing land capabilities for agriculture, forestry, recreation, and wildlife.

CLI analysis reveals that land in the Peace River region is suitable, to varying degrees, for many purposes (Fig. 5.B2): agriculture (mainly grain crops, such as wheat, barley, and oats); forestry (mostly species for pulpwood, such as white spruce, black spruce, and trembling aspen); ungulates (hoofed mammals, such as moose, mule deer, white-tailed deer, and elk); and waterfowl (especially ducks, such as Mallard, Northern Shoveler, Blue-winged Teal, and American Wigeon). Overall, the amounts of land with a high capability for forestry (70%) and agriculture (47%) are relatively high compared with those for ungulates (32%) and waterfowl (3%).

Nearly 55% of the land in the region has high capability to support more than one resource sector (Fig. 5.B3). For example, 40% of the land has high capability for both forestry and agriculture. As only 5% of the region has a high capability solely for agriculture, the rapid expansion of agriculture has inevitably taken place at the expense of other resource sectors.

Land-use trends within this region graphically illustrate the competition and conflict associated with alternative uses of land, as well as the trade-offs that must be made when one resource use is selected over another. As agriculture has been the big winner, forestry has been the big loser (see Fig. 5.B1 and Table 5.B1). By 1986, half of the land best suited for forestry had in fact been converted to agriculture; likewise, 40% of prime ungulate land and 43% of waterfowl habitat had come under the plough. Nearly one-quarter (23%) of the remaining land with high ungulate and waterfowl potential is similarly threatened (Fig. 5.B4).

Agricultural development has not always occurred in an orderly fashion. One-third of all cropland has been developed on land not having a high capability for agriculture, despite the fact that a large amount of high-capability land remains undeveloped. This kind of situation may have occurred because individual farmers expanding their area of cropland tended to use moderate-quality land near their existing land holdings and along transportation routes rather than venturing to better land in more remote areas.

The rapid development of agriculture, combined with the fact that this development has not always occurred on lands best suited for that purpose, has significant implications for the sustainability of other resources. History has shown that the pressure to develop agriculture at the expense of other resource potential is very strong. In parts of southern Ontario, for example, over 90% of presettlement wetlands have been converted mainly to agricultural uses (Snell 1987).

Decision-makers at all levels, from primary producers to politicians, often choose the short-term economic gain of developing land for agriculture rather than development or protection of other resource uses, such as wildlife habitat, whose economic worth may be poorly defined. Although wildlife resources do not share the same economic characteristics as forestry and agriculture, they are nonetheless economically valuable (Filion *et al.* 1989).

Currently, there is no crisis in land use in the region. If development in the Peace River region continues to tilt heavily in favour of agriculture, however, it will reach a point at which wildlife habitats and forestry will not be sustainable. At that time, to ensure resource sustainability, resource managers and planners might well need to protect, in some way, the remaining land.

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[1] Since 1986, there has not been a national land-use monitoring program that tracks changes among various land uses. In the absence of national data, a detailed case study in the Peace River region of Alberta has been prepared to illustrate the competition and conversions that do occur.

Source: A.M. Turner, Environment Canada, personal communication.

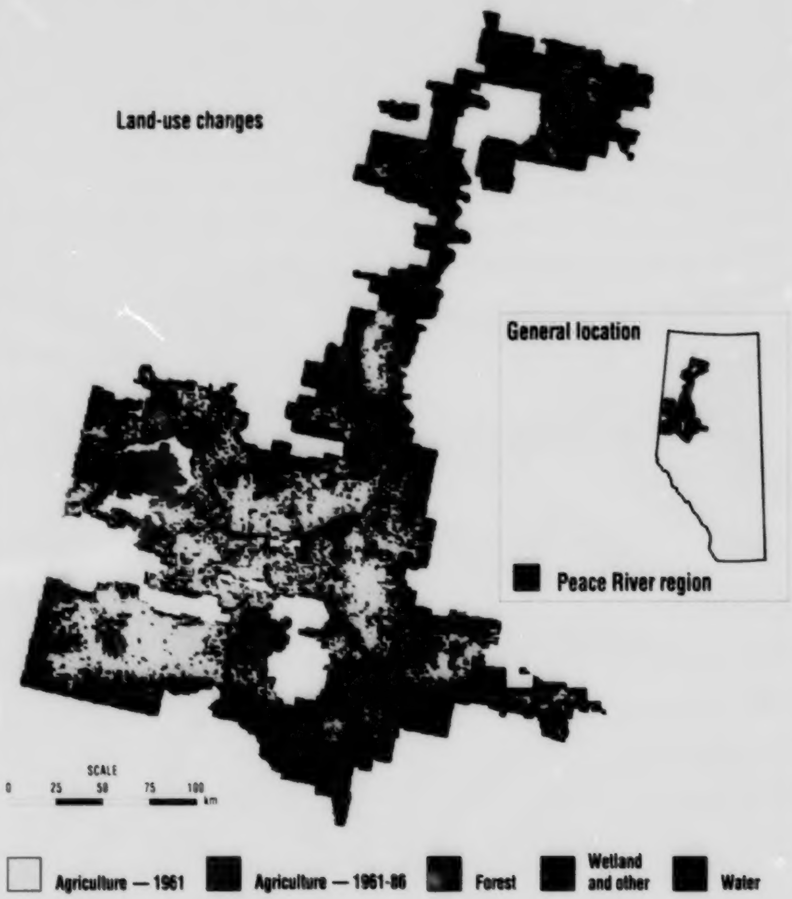
can result in soil erosion, with subsequent land degradation in the areas where soil is redeposited.

The Canada familiar to most of us, therefore, is actually quite urban in nature and is becoming more so all the time. As discussed in Chapter 13, the proportion of Canadians living in cities and towns increased steadily from less than 20% at the time of Confederation (1867) to more than 75% by 1986. Between 1971 and 1986, the urban population grew by about 3 million, absorbing 955 km^2 of rural land in the process. Most of this growth took place, and will likely continue to take place, on the fringes of the large metropolitan centres such as Toronto, Montreal, and Vancouver. The population of the Greater Toronto area, for example, is expected to grow from its 1986 level of 3.73 million to 6.02 million by the year 2021 (Royal Commission on the Future of the Toronto Waterfront 1991). If development patterns in Greater Toronto continue as is, the expected population growth would urbanize an additional 900 km^2 of land by 2021.

In strictly quantitative terms, less than 1% of Canada's total land area is urbanized. Notwithstanding the widespread concern about the continuing growth of the large cities, Table 5.4 indicates that growth of small towns actually consumes more land per capita. From 1981 to 1986, the 9 largest cities in Canada converted only about 22% of the amount of land consumed by the 26 cities in the smallest population class, on a per capita basis. Whether large city or small town, the land-use implications of urban growth are quite disproportionate to the area of land actually occupied.

FIGURE 5.01

General location of Peace River region, Alberta, and land-use changes, 1961–86



Source: Environment Canada, Canada Land Inventory database.

Canada's commons

Land is also used for purposes other than the production of market commodities or as living space. Lands have been identified for outdoor recreation, wildlife habitat, and ecological reserves. Collectively, such lands can be thought of as Canada's commons — they are a public good having benefits for all Canadians, either for their common use (e.g., recreation) or for the protection of their common cultural and natural heritage (e.g., conservation). In total, about 708 000 km^2 of Canada, or 7.1% of its landscape, have been legally protected by federal, provincial, and territorial governments for conservation or recreation (see Chapter 7).

It is difficult to estimate how much land will be needed for Canada's commons. With continuing urban growth, there will probably be a growing demand for land for recreational activities, such as skiing, camping, hiking, fishing, and hunting, and a greater need for protection of wildlife habitat, water supplies, and sensitive or representative ecosystems. However, such alternative land uses often compete directly with other commercial land-based enterprises, such as forest harvesting, agriculture, and urban development. In December 1990, the Government of Canada released its Green Plan, in which it stated that 12% of Canada's total territory would be set aside as protected space, including at least five new national parks by 1996.

[illegible]

Land cover trends in the Peace River region, 1961–86

Land cover class	1961		1986		Change, 1961–86	
	Area (km²)	% of region	Area (km²)	% of region	Area (km²)	By class (%)
Agricultural land[a]	11 861.1	26.3	20 852.8	46.2	+ 8 991.7	+75.8
Forest[b]	32 042.3	71.0	23 059.1	51.1	–9 151.6	–28.6
Wetland	528.4	1.2	498.0	1.1	–30.4	–5.7
Water	457.1	1.0	457.4	1.0	–0.3	+<0.1
Other[c]	213.2	0.5	234.8	0.5	+21.6	+10.1
Total[d]	**45 102.1**	**100.1**	**45 102.1**	**99.9**		

[a] Includes cropland and abandoned cropland (together about 92% of the agricultural land) as well as grazing land, such as pasture and rangeland.

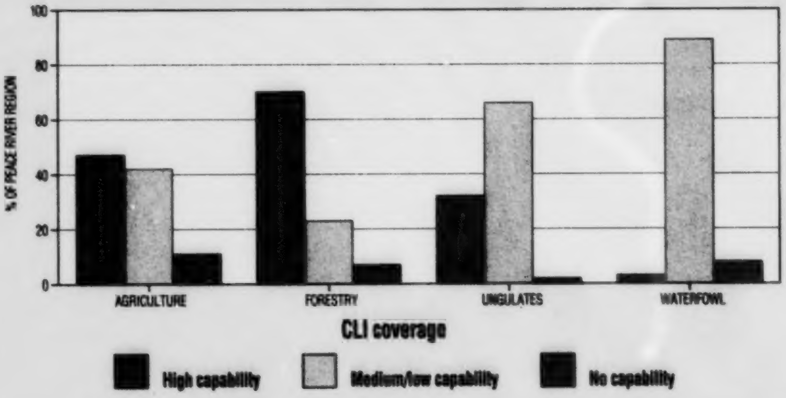
[b] Includes clear-cut forest land.

[c] Includes built-up, bare rock, and bare sand.

[d] Within each land cover class are other land uses that are too small to map at the scale of the study (e.g., oil and gas exploration and development sites, roads, and transmission lines).

FIGURE 5.22

Canada Land Inventory (CLI) land capability for four resource uses in the Peace River region



Source: Environment Canada, Canada Land Inventory, 1990.

Recreation

Opportunities for recreation exist in urban, rural, and wilderness areas. As urban recreation areas become used more intensively, more pressure is being put on the countryside or wilderness. Also, rising urban housing costs often result in more people moving to the country, where they may choose to convert summer residences to all-season dwellings and commute. Inevitably, in making these lifestyle choices, people put pressure on their natural surroundings even as they seek to enjoy them. Adverse environmental impacts of recreation include the following:

- Soil contamination originates from recreational developments such as golf courses, where fertilizers, herbicides, and pesticides are used for course maintenance. Litter and solid waste disposal are major problems related to recreation.
- The siting and construction of seasonal dwellings and large-scale recreational developments can remove topsoil, increase runoff, contribute to flooding, and blight the landscape.
- Concentrated recreational activities can damage plants and habitats through shoreline alterations, land clearing, and so on.

According to Lang and Armour (1980), "The indirect effects of recreation can also adversely affect the environment by causing development where none would have occurred or by speeding it up. Ski slopes attract chalets, lakes and ocean shorelines attract cottages, beaches attract hotels and motels, parks attract cars which need roads plus servicing facilities and a place to park; all attract food, supply and service establishments." The causal factors are not always tourists. Agricultural and farm communities in close proximity to cities are threatened by the use of land by people seeking a rural recreational lifestyle.

IMPACTS ON THE LAND BASE

It is only in the last few years that we have come to acknowledge the obvious: like all else on planet Earth, land is a finite resource. And, in Canada, lands that meet the increasingly complex demands of a wide range of users are limited indeed. Impacts on the land base can be expected to intensify as a result of land degradation, soil contamination, and climatic change.

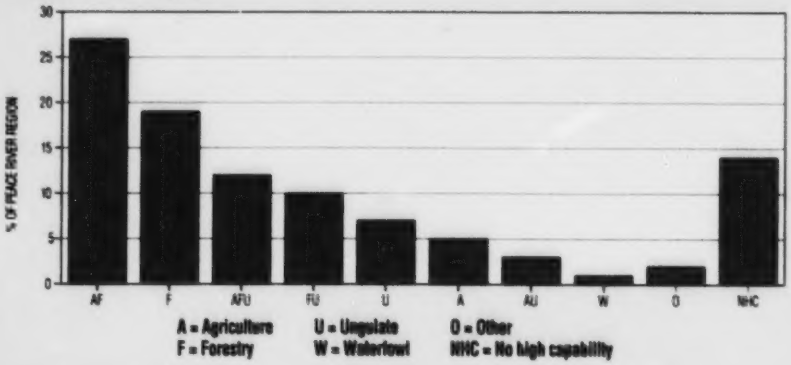
Land degradation

Land degradation occurs when human practices damage the physical nature of the land, reducing or even destroying its long-term productivity and ability to support life and self-sustaining ecosystems. The most common forms of degradation include soil erosion, contamination, salinization, and compaction.

Sometimes land is used in ways that are unsuitable, unsound, or even dangerous, and eventually the quality of the

FIGURE 5.03

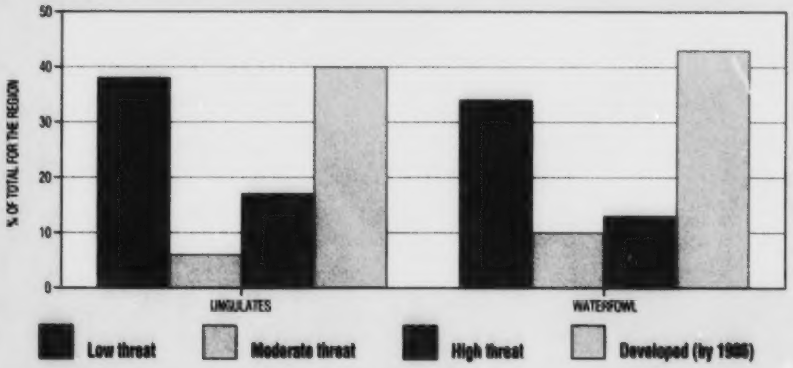
Single and multiple high CLI capabilities as a percentage of the Peace River region



Source: A.M. Turner, Environment Canada, personal communication.

FIGURE 5.04

Loss of high-capability land for ungulates and waterfowl due to agricultural development in the Peace River region, and level of threat to the remaining land



Source: A.M. Turner, Environment Canada, personal communication.

land base becomes degraded. One example is the cultivation of marginal land that is capable only of low crop yields, a practice that is common in the border zone between the productive agricultural lands and the boreal forest. As the last of the virgin productive lands of the prairies were brought under cultivation in the 1960s, agriculture continued to expand onto land physically better suited to uses such as forestry, wildlife habitat, or grazing. Apart from low production, and hence low income generation, cultivating such land inevitably depletes fertility and culminates in eventual abandonment of degraded land.

Soil development is a very slow process that, under natural conditions in Canada, takes place at an average rate of less than 0.5 cm per century. When soil is left exposed through removal of vegetation, however, it can be eroded, transported, and redeposited in a very short period of time. The rapid settlement of the Canadian prairies in the 1920s and the practice of ploughing vast areas of native grasslands without regard for soil stability or cropping suitability quickly resulted in drought, grasshoppers, wheat rust, and wind erosion. Soil loss on the prairies has continued, despite attempts to prevent it (see Chapter 17).

Soil erosion and depletion of nutrients and organic matter are also encouraged by other agricultural practices, such as tillage on steep or very undulating slopes, removal of windbreaks and vegetation along waterways, and the use of large machinery. In upland areas, such practices expose the soil to wind and water erosion; in lower, moister areas, to salinization; in both, to compaction through the untimely or repeated use of heavy machinery. In New Brunswick, erosion has severely affected one-third of the land on which potatoes are grown intensively. On some potato fields, up to 12 cm of topsoil have been lost in the past 20 years (Simpson-Lewis *et al.* 1983).

Degradation of agricultural lands results in lower crop yields, persistent weed problems, and the need for ever-larger quantities of fertilizer (Dodge 1989). The annual economic impact of soil erosion on the prairies has been estimated at $370 million, with projected increases to $400 million by 1991 (Agriculture Canada 1985). In Saskatchewan, an estimated 80 000 km^2 are at high risk of wind and water erosion (Saskatchewan Environment and Public Safety 1991). The cumulative economic impacts of salinization — the accumulation of salt at or near the surface of soils — were estimated to be between $100 million and $300 million, increasing by at least $1 million annually. Soil salinity occurs naturally in Saskatchewan, where approximately 20 000 km^2 are affected to some degree and 2 400 km^2 have seriously impaired productivity (Saskatchewan Environment and Public Safety 1991). The direct economic impacts of soil degradation in central and eastern Canada are considered to be only slightly lower than on the prairies and are also expected to increase. According to Agriculture Canada (1985), "It is not known precisely when and where the annual economic impacts of soil degradation will eliminate the feasibility of economic production.... [In] some parts of the country it has already happened and once-fertile lands in New Brunswick and on the prairies have had to be abandoned. This process is likely to occur in other regions if current crop management practices continue."

Soil contamination

A wide range of human activities result in contamination of Canada's soils. Farmers and foresters spray pesticides and fertilizers onto the land. Industrial and vehicle emissions are deposited on the land, acidifying and otherwise altering the composition of the soil, with possible consequences for ecosystems and the land base (Canada Committee on Ecological Land Classification 1989).

Industrial and municipal discharges, on-site burial of wastes, frequent chemical leaks and small spills, major spills, and underground storage of toxic materials can also lead to local contamination of the land (Huestis 1990). Recent dramatic examples are the Hagersville, Ontario, tire fire and the fire at the St. Basile-le-Grand, Quebec, PCB storage site (see Chapter 21). Such contamination is not limited to southern Canada; PCB-contaminated wastes have been discovered at abandoned and active military sites across the Canadian Arctic (Huestis 1990) (see Chapter 15).

Climatic change

The greatest potential challenge to Canada's land resource may come from climatic change. The global accumulation of carbon dioxide and other "greenhouse gases" in the atmosphere, with the resultant prospect of a warmer and perhaps drier climate, has far-reaching implications (see Chapter 22).

With climatic warming will come changes in other climatic elements such as precipitation and evaporation. Although average global precipitation and evaporation are expected to increase, regional variations could occur that could lead to significant changes in water availability. Some areas, such as the southern prairies, may become substantially drier, whereas others, such as parts of the Arctic, could become much wetter. This has implications for soil moisture conditions and for resources and activities dependent on soil moisture, such as agriculture and forestry.

TABLE 5.4

Growth and change within urban-centred regions (UCRs) grouped by population class, 1981–86

Population class	No. of UCRs	Area increase (%)	Population density (population/ha)	Population increase (%)	Rate of land conversion (ha/1 000 population change)
25 000–50 000	26	3.3	9.0	1.5	242
50 001–100 000	18	4.0	9.8	2.9	141
100 001–250 000	13	4.9	12.8	3.6	104
250 001–500 000	4	3.2	12.4	5.2	50
> 500 000	9	6.6	19.5	6.3	53
Average for 70 UCRs		**5.4**	**16.5**	**5.4**	**64**

Source: Warren *et al.* (1989).

A warmer climate may result in a significant rise in sea levels (Egginton and Andrews 1989; Intergovernmental Panel on Climate Change 1990). As temperatures rise globally, glaciers and ice caps will melt more rapidly and ocean waters will expand. Estimates of rise in sea level range from a few tens of centimetres to a metre or more over the next 100 years. Because Canada has the world's longest coastline, the impact of any rise in sea level is of great concern. Some specific consequences for land include a net loss in land area through inundation and erosion, including the loss of recreational beaches and coastal wildlife habitat. In particular, increased coastline recession could occur where ground materials are unconsolidated and ice-rich in nature, such as in the Mackenzie River delta and along the coastline of the Beaufort Sea.

LAND-USE COMPETITION AND CONFLICT

Land lends itself to many uses. Inevitably, therefore, the land resource is the source of competition and conflict. Land-use competition arises where the same area of land is in demand for different purposes. Land-use conflict occurs where one use of land is incompatible with other uses of the same land or somehow impinges on the uses of adjacent or nearby land. Both usually arise from the fact that "usable" land — land that combines valuable qualities and is accessible — becomes an economic commodity in increasingly short supply. More and more land-based activities must be accommodated within a limited space; predictably, the result is conflict (Simpson-Lewis *et al.* 1983).

Urban growth on agricultural land

It is often claimed that, on a clear day, approximately one-third of Canada's best farmland can be seen from the top of Toronto's CN Tower. Settlements naturally grow up around the best farming areas and eventually cover the very soils that gave birth to them. Cities like Vancouver, Calgary, Edmonton, Regina, Winnipeg, London, Toronto, and Montreal continue to grow on our limited supply of productive agricultural land. More specifically, from 1981 to 1986, the Toronto urban-centred region absorbed 100 km^2 of prime agricultural land; Edmonton, 40 km^2; Montreal, approximately 6 km^2; and Vancouver, 6 km^2 (Warren *et al.* 1989).

Table 5.6

Total rural land and prime agricultural land converted in Canada's 70 urban-centred regions (UCRs) between 1966 and 1986

Province	No. of UCRs	Total rural land (TRL) (km²)	Prime agricultural land km²	Prime agricultural land % of TRL
British Columbia	7	453.30	93.60	21
Alberta	5	516.91	314.29	61
Saskatchewan	4	106.13	69.18	65
Manitoba	2	130.46	114.47	88
Ontario	26	1 059.52	830.40	78
Quebec	19	505.87	249.12	49
New Brunswick	3	108.48	24.25	22
Nova Scotia	2	80.43	30.47	38
Prince Edward Island	1	22.80	21.97	96
Newfoundland	1	30.50	0.15	>1
All provinces	**70**	**3 014.40**	**1 747.90**	**58**

Source: Warren *et al.* (1989).

The loss of prime farmland to both direct and indirect urban uses has resulted in significant declines in the area of improved farmland in Ontario, Alberta, and Quebec between 1966 and 1986 (Table 5.5). Conversion of farmland is of even more serious consequence in those areas of Canada suitable for growing specialty crops, such as the Niagara and Okanagan fruit-growing areas. The highly visible spread of urban uses over agricultural land — the well-named urban sprawl — has sparked heated public debate for decades. Several provinces, notably British Columbia, Quebec, and Newfoundland, have enacted specific legislation to protect farmland. Pressures continue even in British Columbia, however, which enacted the first, and still the strongest, piece of land protection legislation — the *Agricultural Land Commission Act*, under which agricultural reserves are established. As recently as 1989, the release of about 1.2 km² of prime agricultural land just outside the City of Vancouver, in the Township of Richmond, sparked a phenomenal public outcry.

Living in the urban shadow

There are also indirect impacts of urban expansion on agricultural land use, sometimes called the urban shadow effect. Land developers, speculators, golf course proponents, country estate seekers, and a variety of commercial and industrial enterprises compete with agriculture for land beyond the urban edge, raising prices to a level at which farming ceases to be an economically viable use of the land. Eventually, farming comes to be seen as a mere holding action, productivity declines as investment is reduced, and the land may actually go out of production altogether, long before the builder arrives.

Conflicts also arise when farms and suburban subdivisions are next door to each other, which is increasingly the case. Subdivision residents often complain of odours when manure is being spread and of traffic jams when a farmer moves hay down a road. In some instances, these objections have forced farmers out of business or to undertake costly renovations.

The extent of the urban shadow is much greater than that of the urban core itself. As an example, take the highly urbanized Windsor-to-Quebec City corridor. In 1981, subdivisions, classed as "semi-urban," covered 34 000 km², compared with 27 000 km² classified as "urban" (Yeates 1985). There is a need to adopt measures to reduce or eliminate the effect of the urban shadow as well as to preserve the land base itself (see Chapter 13).

Land conservation

Market values for land often override other social, ecological, or cultural values attached to it. Wetlands were long seen as valueless in the conventional market sense, except perhaps for duck hunting, and it was common to drain them for cultivation. Drainage of wetlands was even encouraged by government programs, such as the 1948 *Maritime Marshlands Reclamation Act*. As a result, an estimated 65% of Atlantic coastal marshes, 70% of the wetlands of southern Ontario and the Prairies, and 80% of the Fraser River delta wetlands in British Columbia have been drained or otherwise "recovered," mainly for agricultural use (Environment Canada 1986). In some provinces, this process continues, still aided by government programs. However, the ecological and hydrological value of wetlands, as distinct from their economic value, is now better understood, and attempts are being made to preserve what wetlands remain. In some cases, there are even efforts to restore former wetlands or create new ones (see Chapter 26).

Market versus nonmarket values are also central to the growing competition between forestry and other users of forested lands. Canada's forests can no longer be seen as merely a place to procure timber and wood fibre. They embody other intrinsic values, related to outdoor recreation, the preservation of wildlife habitat, and conservation of sensitive ecosystems.

LAND-USE PLANNING

Land-use conflicts, such as the loss of agricultural land to urban sprawl and the extractive versus subsistence use of resources, are nothing new. Their seeds were sown more than a century ago, as the country and economy reached into new frontiers. However, our concepts of land and the related issue of land use have expanded considerably in recent years. More than any other specific event, the release of the 1987 World Commission on Environment and Development report, entitled *Our common future*, gave focus to the current, still evolving, perspective on land and our use of it. It might be said that sustainable development is based on the concept of land as a common habitat for all living things, not just a short-term joint bank account upon which we can draw at will for our exclusive purpose.

There is a climate for change in our approach to the land from one of exploitation to one of stewardship and accommodation. However, we must have mechanisms for translating these principles into action. The challenge of how best to use the land — the essence of land-use planning — is not a simple one.

Land capabilities must be evaluated; the economics of various land-use activities must be assessed; political, social, and scientific concerns must be reviewed; the needs of the regions and the country as a whole must be carefully determined; and priorities or guidelines must be established.

There is a shared responsibility among governments, industry, and individuals to find lasting solutions to Canadian environmental issues. Environmental stewardship is shared among all users of Canada's land resource.

The provinces are the major administrators of Canada's natural resources. An integrated rather than a sector-by-sector approach to land and water planning is being practised in all regions of Canada. Through the integration of Canada's land-use sectors, we can better coordinate our nation's land heritage to help realize an ecological well-being.

Acting on the recommendations of the World Commission on Environment and Development, Canada established its Task Force on Environment and Economy. The task force, in turn, recommended that multisectoral round tables be established in each of the provinces and territories, which has now been accomplished (National Task Force on Environment and Economy 1987). The establishment of round tables can be a significant step towards more sustainable use of land, in that it brings together a wide range of stakeholders, including politicians, representatives of the private sector, and public environmental interest groups, in a common forum to resolve basic issues related to changing perceptions and values of land and land use. Canada's Green Plan (Government of Canada 1990) further contributes to this goal by incorporating the fundamental principle of sustainable development: "For the benefit of current and future generations, all Canadians must act to help sustain our renewable resources and the ecosystems upon which they depend."

Aboriginal peoples

Historically, aboriginal peoples did not believe that they could own the land any more than they could own the sky. People merely shared the land with other living organisms. For thousands of years, hunting, trapping, fishing, and other harvesting of the land's living resources have constituted the traditional economy and way of life of aboriginal Canadians. These activities remain fundamentally important land uses over vast areas of Canada. They are integral to the Indian and Inuit cultures and are viewed as the key to their independence and their ability to attain a reasonable standard of living.

Clearly, the issue of sustainable use of land cannot be separated from the issue of social justice and fair access to the land's resources. Currently, the most critical demonstration of this challenge is the national debate surrounding aboriginal rights and land claims.

Two basic types of claims exist. Comprehensive claims are based on claims to aboriginal title arising from traditional use and occupancy of land. Such claims arise in the Northwest Territories, Yukon, Labrador, most of British Columbia, and northern Quebec, where aboriginal title has not been previously dealt with by treaty or other means. They normally involve native Indian or Inuit groups (e.g., tribal councils, bands, or communities) that assert aboriginal title to a specific geographic area. Settlement agreements are comprehensive in scope and include such elements as land title, specified hunting, fishing, and trapping rights, and financial compensation, as well as other rights and benefits (Indian and Northern Affairs Canada 1991). For example, under the James Bay and Northern Quebec Agreement of 1975, the 10 000 Cree and Inuit of northern Quebec received title to a total of 14 000 km^2 of community lands, together with exclusive hunting and trapping rights over a further 150 000 km^2, representing 1.3% and 14%, respectively, of the area covered by the agreement. Under the Inuvialuit Final Agreement of 1984, the 2 000 Inuvialuit of the Mackenzie delta region obtained either full or limited title to approximately 20% of their 435 000-km^2 area of traditional use and occupancy, together with special hunting and trapping rights in the entire area.

Specific claims relate to Canada's lawful obligations regarding the administration of land and other Indian assets and to the fulfilment of treaties, other agreements, or the *Indian Act* (Indian and Northern Affairs Canada 1990). As of March 31, 1991, 606 specific claims had been submitted, of which 47 had been settled by negotiation. Federal financial compensation amounted to $129.3 million, and the various provinces provided $37.5 million and 57 894.4 km^2 of land. As of the same date, 18 claims were in the settlement negotiation phase, 49 had been accepted for negotiations, and the rest were at various other stages of assessment (e.g., suspended, under litigation, awaiting review, referred for redress under other government programs). Some notable settlements of the late 1980s with respect to treaty land entitlement or reserve lands include:

- the Fond du Lac Band — 123.9 km^2;
- Sturgeon Lake — 65.6 km^2;
- the Cree Band of Fort Chipewyan — 49.7 km^2; and
- Whitefish Lake — 22.3 km^2.

In total, Canada's 596 Indian bands have 2 261 Indian reserves covering approximately 27 110 km^2, an area about half the size of Nova Scotia (Indian and Northern Affairs Canada 1990).

TABLE 5.6

Ownership (tenure) of lands in Canada

		% of total area		
		Crown land		
Province or territory	Total area[a] (km²)	Federal[b]	Provincial or territorial[c]	Private land[d]
Newfoundland	371 690	0.7	94.9	4.4
Prince Edward Island	5 660	0.8	12.1	87.1
Nova Scotia	52 840	2.9	29.8	67.3
New Brunswick	72 090	3.0	42.9	54.1
Quebec	1 356 790	0.2	92.1	7.7
Ontario	891 190	0.9	88.0	11.1
Manitoba	548 360	0.8	78.0	21.2
Saskatchewan	570 700	2.4	57.7	37.9
Alberta	644 390	9.6	62.6	27.8
British Columbia	929 730	0.9	93.3	5.8
Yukon	478 970	99.8	0.175	0.031
Northwest Territories	3 293 020	99.9	0.086	0.002
Canada	**9 215 430**	**40.3**	**50.0**	**9.7**

[a] From Statistics Canada (1990). All figures have been rounded to the nearest 10 to reflect their approximate nature.

[b] Includes federal Crown lands, national parks, and federal forest experiment stations.

[c] Includes provincial or territorial areas, provincial parks, and provincial forests.

[d] Includes privately owned land or land in process of alienation from the Crown.

Federal government

Although the federal government controls very little land, at least in the southern, more densely populated regions of the country (Table 5.6), its ability to shape land use in Canada is substantial and diverse (Richardson 1989). In the mid-1970s, the Government of Canada, recognizing the importance of land-use planning, began developing a land-use policy applicable to all federal activities. In 1980, the Federal Policy on Land Use was adopted (Government of Canada 1980). With its 6 guiding principles, 11 policy statements, and 10 land-use guidelines, the policy focuses on minimizing environmental impacts of decisions related to the land resource and ecosystems. The Federal Policy on Land Use is part of a federal land management process that ensures the adoption of sustainable development principles in the acquisition, use, and disposal of land by the Government of Canada. Individual agencies are changing management processes to respond to these new principles. For example, the Department of Public Works and the Department of National Defence have amended their environmental impact assessment screening processes to take into account the Federal Policy on Land Use.

During the 1980s and 1990s, governments have enacted increasingly stringent legislation to regulate environmentally damaging practices, such as the discharge, dumping, and spillage of pollutants onto the land and the spraying of herbicides and pesticides. Since 1988, the *Canadian Environmental Protection Act* has empowered the federal Minister of the Environment to regulate environmental pollution on a national basis. It adopts an ecosystem approach, looking at terrestrial, atmospheric, freshwater, and marine resources; it applies to all federal lands and thus can be utilized to help safeguard such lands from various forms of pollution.

Provincial and territorial governments

The processes of land-use planning and environmental impact assessment are found in each province and territory and the northern land claims settlement areas. There are various planning and review mechanisms through which sustainable development principles are applied. In the cases of Prince Edward Island and Yukon, these take the form of a government-endorsed conservation strategy. A number of other provinces are preparing conservation or sustainable development strategies that will define common goals for the planning processes. In the Nunavut comprehensive northern land claims settlement region (Northwest Territories), common goals supportive of sustainable development have been made explicit for land-use planning and environmental impact assessment.

The planning approach that appears to be evolving to meet the challenges facing Canadians can be called strategic land-use planning. This approach is different from the detailed land-use planning done in the past, in that it approaches land-use issues from a more broadly based, comprehensive, and long-term perspective.

Across Canada, significant steps have already been taken towards developing a new strategic approach to land-use planning. For example, under British Columbia's *Land Act*, provincial Crown lands are planned and managed to reflect the most suitable use of the land. In Alberta, integrated resource planning is applied to public land and resource management. Under the *Natural Resources Conservation Board Act*, projects dealing with, for example, the forest industry, recreation, tourism, mining, and water management are reviewed to determine their effects on the province's natural resources. Manitoba has developed a Land and Water Strategy as part of a provincial sustainable development strategy.

State of the environment reports are a source of environmental information, including land-use issues. Quebec was the first province to issue such a report in 1988. Both Manitoba and Saskatchewan published reports in 1991.

Under Ontario's *Planning Act*, provincial policy statements on land-use planning for housing, floodplains, and mineral aggregates have been approved. Policy statements on wetlands and foodland preservation are being developed. The Ministry of Natural Resources applies land-use plans throughout the province based on integrated resource management. New Brunswick established a Land and Water Use Advisory Committee, under the *Clean Water Act*, to advise on major developments and reduce conflicts. New Brunswick, Nova Scotia, and Prince Edward Island established the Maritime Provinces Land Information Corporation to deliver land information to governments, firms, and individuals. Newfoundland is evaluating an integrated resource planning process.

Municipal and regional governments

In the jurisdictional hierarchy of planning, the provinces have delegated many land-use functions (e.g., layout of roads, provision of water and sewer services) to municipalities. Land-use planning is applied in eight provinces at both the municipal and regional levels and in two provinces at the municipal level only. In the territories, land-use planning is applied mainly at the regional level, as it is in the land claims settlement areas. Most provinces have also instituted some form of regional or intermunicipal planning, involving cooperation between the municipal councils.

Traditionally, local land-use planning focused on specific community needs, which often resulted in narrowly defined priorities, such as enhancing the property tax base or controlling servicing costs — issues divorced from the state of the environment. Recently, however, citizens and their elected representatives have indicated a growing awareness of the seriousness of overburdened landfill sites, loss of regional open space, and other land issues. Some cities have responded enthusiastically to the call for sustainable development and are incorporating such concerns into their land-use plans. The Municipality of Burnaby in British Columbia, for example, has decided to hire an ecosystems planner and is preparing a state of the environment report that will be used in a review of its Official Community Plan. The City of Ottawa also envisions sustainable development as the main guiding principle of its official plan, which will include a conservation strategy as one component. Other local jurisdictions, such as the Saguenay/Lac St-Jean region of Quebec, are proposing the development of comprehensive sustainable development strategies, which would encompass land-use planning.

Along a different route towards sustainability, the Province of Ontario is proposing a "model community," Seaton, on Crown land near Pickering (Winter 1990). Environmental groups will have an opportunity to participate in the planning of the new community, which is intended to promote green space, watershed protection, energy efficiency, waste reduction, public transportation, and other environmental values. The Seaton experiment is an initiative towards environmentally sustainable urban development.

CHALLENGES TO SUSTAINABLE USE OF LAND

Throughout Canada, there have been many local successes in the struggle to protect or restore land. For example, extensive areas blighted by smelter emissions around Sudbury have been successfully replanted with grass, shrubs, and trees. Worked-out gravel pits, such as the Royal Botanical Gardens in Hamilton and the Butchart Gardens in Victoria, have been rehabilitated and converted to places of flowering beauty for the enjoyment of residents and visitors. Significant areas of land have also been designated for special protection: national, provincial, and territorial parks; wildlife reserves and migratory bird sanctuaries; and unique heritage or ecological features such as the Niagara Escarpment (see Box 5.2). On a broader scale, however, incredible obstacles remain along the path to sustainable use of the land.

Inadequate knowledge of the land base

At every level — national, provincial, regional, and local — our knowledge of the land base itself is inadequate. In many instances, basic resource inventories, from which land-use interpretations can be made, remain incomplete or are outdated. Following the termination of the national Canada Land Use Monitoring Program of Environment Canada, in place from 1978 to 1988, there is a need for national data indicating how much land is used and how land uses change from year to year. Nationally, Canada has not determined how much land will be needed for different purposes in the future, nor is there agreement on how to establish the true value of various land uses, to compare with those established by the market. There is also the need to establish national concrete objectives, criteria, and guidelines for land use and management in order to achieve sustainability, supported by indicators to measure progress towards it.

Jurisdictional maze

The challenge of working towards sustainable development is further hampered by the jurisdictional maze surrounding responsibility for land and land use. Of Canada's total land area, 40% remains as federal Crown land (almost all of it in the northern territories), whereas 50% comprises provincial Crown land. Only about 10% of Canada's land base is privately owned (see Table 5.6). The federal, provincial/territorial, and municipal levels of government all have important and somewhat overlapping responsibilities affecting land and the way it is used; at each level, these responsibilities are exercised by several different agencies. As a consequence, a particular tract of land may receive the attention of many different government and nongovernment agencies, each with its own objectives for that land (e.g., providing

BOX 5.2

Niagara Escarpment Plan: in the face of adversity

Clinging to the 30-m limestone cliffs of the Niagara escarpment near Milton, Ontario, are the province's most venerable trees (Reschke 1990). The 700-year-old eastern white cedars are distorted and stunted by centuries of wind, snow, and rain. This curious flora is just one of the unique ecological features associated with the escarpment.

Running from Queenston in the south to Tobermory in the north, the 725-km-long escarpment and lands in its vicinity cover 1 830 km^2. It encompasses enormous scenic, scientific, and recreational value. The Bruce hiking trail traverses much of its length, through forest, farmland, and town; it contains a wealth of flora and fauna, with unique natural features, like the massasauga, a rattlesnake and Ontario's only venomous snake. In addition, the escarpment's rampart, which, 450 million years ago, formed the shoreline of an ancient sea, today provides the most dramatic landscape feature in southern Ontario.

Located on the edge of Canada's so-called Golden Horseshoe, the escarpment was not only appreciated by sightseers but also jealously regarded by developers. At the same time, the area has long supported orchards and vineyards and been the source of mineral aggregates. These multiple land-use conflicts were eroding its natural qualities and ultimately led to a public demand for its preservation.

In response, in 1967, the Ontario government initiated a comprehensive land-use study. After 17 years of debate among the many users of the area, including hikers, gravel pit operators, botanists, landowners, and municipal councils, the Niagara Escarpment Plan was approved by the Ontario Cabinet in 1984.

The plan is a classic example of the use of land planning to protect and conserve noneconomic values and is Canada's first large-scale environmental land-use plan. Although the long and rigorous struggle that put the Niagara Escarpment Plan in place illustrates the conflicts regarding land use in society, it also demonstrates that patience, persistence, and political will can overcome differences of opinion and values (Richardson 1989).

transportation corridors, increasing crop production, or protecting the habitat of endangered species).

The current multiplicity of mandates of land-related agencies can have far-reaching implications. In any given area, the land may be subject to numerous policies, plans, and programs that may address land issues in a variety of ways. Amidst the negotiations over who gets to use land for what purpose, the concept and value of the land itself can get lost in the shuffle. In the formulation of economic policy or in trade negotiations, for example, economic sectors such as agriculture or forestry are often considered in isolation from their land base. Similarly, economic functions of government are separated from those concerned with the management of land, resources, and the environment. As a consequence, little attention is given to the link between economic policy and land use.

The true value of land: seeking a new definition

A major challenge to ecologically sustainable use of land is individual and corporate attitudes and values. Although these are changing in favour of increased environmental protection, there is still much that needs to be unlearned, as revealed even by the language we use when referring to land. A tract of land is called a parcel or a property. Exploiting the land's resources is called development, even though the positive connotations of the word may be inappropriate. Unless carefully qualified, the value of land is assumed to mean its monetary value on the real-estate market. Further, the market value is usually assumed to take precedence over the land's other values (i.e., ecological, scenic, heritage). A public body wishing to preserve those values by acquiring the land must pay the market price, and it is considered the right of the owner to profit financially from such circumstances.

What people do with their land can have environmental and social implications for others. Thus, most people recognize that some public control over private property use is legitimate. The level of such control, however, is highly contentious. For example, a provincial or municipal agency charged with making a decision on whether a private landowner can convert farmland to urban use is likely to consider such matters as the need for housing, the availability and cost of water and sewer services, sites for parks and schools, and perhaps the agricultural quality of the land. However, the agency is much more likely to consider the "right" of the landowner and the developer to make a profit than to consider the cumulative effects of urbanization on watershed stream flow and water quality or upon aesthetic enjoyment of a pastoral landscape. The issue of how much regulatory control is acceptable or desirable, including the related issue of compensation for loss of value, must be satisfactorily resolved if the use of land is to be sustainable for everyone and not merely profitable for a few.

CONCLUSIONS

Land would appear to be something Canadians enjoy in overwhelming abundance. To some degree, this is an illusion, because much of the land base does not lend itself to the demands of modern society. Further, our use of land has often ignored the fragile character of the land base itself and led to the degradation of many of the most productive tracts. One-eighth of our forests can no longer be considered productive, for example, and about 20% of our farmland is deteriorating, as a result of modern agricultural practices (Keating

1989). Furthermore, much of the very best farmland, which has always been in extremely short supply in Canada, is continuing to disappear under pressures of urban expansion.

Protection of representative ecosystems is essential, but the development of land-use models that allow for multiple use of the land and, at the same time, preserve the principles of sustainability presents an even greater challenge. There are successful examples of this kind of land use, such as the Niagara Escarpment Plan, which strike a balance between protection and environmentally compatible development, but at present these are too few and isolated.

Land-use strategies throughout Canada should be based on common principles. The most important among these is the anticipation and prevention of environmental degradation. The successful anticipation of future multiple land-use issues should be based on the ability to forecast the possible consequences of a given action. The state of our land resource depends upon all Canadians having and applying a knowledge of environmental processes that will ensure the future prosperity of Canada's lands and ecosystems.

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6

COURTESY OF D. GUNN, OAKVILLE

HIGHLIGHTS

Agriculture, by transforming natural woodland and prairie into intensively managed farmland and by exterminating organisms that are perceived to be pests or weeds, has contributed to the endangered or threatened status of at least 25 species in Canada. The forest industry has been a direct factor in the endangered or threatened status of 10 or more species. Hunting, fishing, and trapping helped to put at least 16 Canadian species at risk, mostly before the advent of modern wildlife practices. The frequently allied forces of urbanization and industrial development have occupied or polluted the living space of 12 or more endangered or threatened species in Canada.

■

The stresses of human activity on wildlife can be further illustrated by comparing Canada's major life zones. The two largest but least populous, the Arctic and Boreal zones, possess the fewest species in trouble. Conversely, the Great Lakes/St. Lawrence zone, the smallest but with the most people, is home to the most endangered or threatened species.

■

The North American Waterfowl Management Plan aims to increase continental waterfowl populations by securing and enhancing wetland breeding, staging, and wintering habitat. Funded by federal, state, provincial, and private sponsors, its current Canadian budget of over $60 million annually makes it by far the largest wildlife population support program in Canada.

■

The task of reviewing scientific reports on native plants and animals, to determine which species merit designation as endangered, threatened, or vulnerable, falls to the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) — a body composed of federal, provincial, and territorial wildlife management agencies and three major nongovernment organizations, the Canadian Nature Federation, the Canadian Wildlife Federation, and World Wildlife Fund Canada.

■

Government and nongovernment organizations also make up the Committee on Recovery of Nationally Endangered Wildlife (RENEW), which assesses the practical prospects for saving endangered species.

■

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INTRODUCTION

Maintaining Canada's biological diversity, meaning healthy populations of all wildlife, is a key aspect of maintaining the health of the country's environment. As a way of providing support to life forms that have not traditionally been included in government environmental policies, the Wildlife Ministers' Council of Canada (1990) has broadened the definition of the term "wildlife" to include not only the vertebrate species (mammals, birds, fish, amphibians, and reptiles), but also invertebrates, vascular plants, algae, fungi, bacteria, and all other wild living organisms.

> “
> **Our fate is connected to the animals.**
> ”
> — Rachel Carson (1962)

This chapter offers an overview of the state of Canada's wildlife, largely as perceived through an assessment of conditions and trends in the country's biological diversity. Where available, population data are discussed in the framework of seven broad life zones. The chapter concludes with a brief look at a number of conservation initiatives that aim to improve the lot of wildlife.

BIOLOGICAL DIVERSITY

What is biological diversity?

Biological diversity, or biodiversity, is the term used to cover the variety and variability that exist among living organisms and the ecological complexes in which they occur (Office of Technology Assessment 1987). It includes the entire, rich tapestry of life: the global biosphere, particular ecosystems, individual species, and genetic variation within species. The term "wildlife" in this chapter should be understood to include all nondomesticated, living organisms in Canada, as summarized in Table 6.1 and defined in the Wildlife Policy for Canada (Wildlife Ministers' Council of Canada 1990). Thus defined, Canada's wildlife population encompasses nearly 1 950 known species of vertebrate animals and about 4 200 known species of vascular plants, about 3 300 of which are native to Canada. Invertebrates have been studied less thoroughly but are estimated to number about 95 000 species. Close to 34 000 species of insects have been reported in Canada, and nearly as many again are thought to exist but have not yet been described or classified (Danks 1988).

Maintaining biological diversity is part of a larger environmental goal: protecting the integrity of natural ecosystems and the health of the Ecosphere as a whole. The "integrity" of an ecosystem is reflected in its ability to support balanced, adaptive wildlife communities whose species composition and functions are appropriate to a given habitat (Karr and Dudley 1981). "Ecological health" refers to the stability of ecosystems, their ability to realize their inherent potential and repair themselves when disturbed, and their need for minimal external support (Karr *et al.* 1986). The health of wildlife is a major indicator of ecological health.

Using biological diversity as a yardstick for the well-being of Canada's environment is a complex exercise. Individuals, populations, communities, and ecosystems must all be considered; in many instances, however, the data that might provide insight are sparse or unavailable. Particularly lacking is information about the less familiar groups, such as invertebrate animals and nonvascular plants (Table 6.1), and about the interactions among organisms that are essential to ensure healthy ecosystems.

The importance of biological diversity

Most Canadians value wild mammals, birds, and fish. Few, however, appreciate the powerful ecological roles that are played by bacteria, algae, fungi, and invertebrates in essential ecological processes, such as oxygen generation, nitrogen fixation, nutrient cycling, waste decomposition, water cleansing, and soil formation. A single teaspoon of soil may support 10 million bacteria and over 2 km of microscopic fungal filaments (Hill 1989). The health and abundance of vertebrate species, including humans, cannot be separated from the well-being of the invertebrates, plants, and microorganisms upon which they ultimately depend.

Viewed as a resource, wildlife provides a wide range of social and economic benefits to Canadians. Many who follow traditional lifestyles still depend directly on wild animals as important sources of food, clothing, and income. A far larger proportion of the human population derives indirect economic gain from the harvesting and processing of native wildlife species to produce a variety of commercial products, ranging from food and fashions to medicines, paper, and construction materials. The economic value of the wildlife resource is enormous. For example, the marketed value of Canadian fish amounted to more than $3.2 billion in 1988, and angling added a further $14.4 billion to the Canadian economy (see Chapter 8). In 1988, the total value of forestry products was about $49 billion, and in 1989, forestry contributed $19.5 billion to Canada's balance of trade — more than agriculture, mining, and energy combined (Forestry Canada 1991). Both industries depend almost exclusively upon the sustainability of wild animals and plants for their continued existence.

Activities that are more consciously focused on wildlife also provide significant economic benefits to the country as a whole. For example, in 1987, 1.7 million people (8.4% of the population) hunted, 5.6 million (28.1%) fished for pleasure, 15.2 million (75.9%) watched, photographed, or studied wildlife, and 17.1 million (85.5%) watched films or television programs about wildlife or read books and magazines on this subject. Canadians spent an estimated $9.4 billion on all these activities combined. This expenditure included purchases of licences and equipment for hunting and fishing, outdoor clothing, binoculars, and bird feeders, as well as costs related to transportation and hotels. As a result, in 1987, $11.5 billion was contributed to Canada's gross domestic product, $4.5 billion of government revenue was generated, and 284 000 jobs were sustained (Filion *et al.* 1990).

Table 6.1

Summary of the biological diversity of wild species in Canada

Plant and animal groups	Known species[a]	Suspected species[a]	Principal pressures/stresses
Algae and diatoms	5 323	2 800	Water pollution
Slime molds, fungi, and lichens	11 400	3 600	Atmospheric pollution
Mosses and liverworts	965	50	Habitat reduction, especially deforestation and loss of wetlands
Ferns and fern allies	141	15	Habitat reduction
Vascular plants (about 78% native)	4 187[b]	100	Habitat reduction
Molluscs	1 121	100	Water quality changes
Crustaceans	3 008	1 100	Overharvesting, water pollution
Insects	33 755	32 800	Habitat change, biocides
Spiders, mites, and ticks	3 171	7 700	Habitat change, biocides
Other invertebrates	6 879	5 000	Habitat change, biocides
Sharks, bony fish, and lampreys	1 091	513	Habitat destruction, water pollution, overharvesting
Amphibians and reptiles	83	2	Habitat destruction, acid precipitation, overharvesting
Birds	578	0	Habitat change and loss, biocides, competition from nonnative species, hunting
Mammals (excluding humans)	193	0	Habitat change and loss, hunting
Total	**71 895**	**53 780**	

[a] "Known species" are those that have already been named and described, whereas "suspected species" are those that are estimated to exist but have not been named or described. Bacteria and viruses also contribute part of Canada's biological diversity. Almost 170 000 species are suspected to exist in the country, but only about 2 200 species have even been named.

[b] Of the species total for vascular plants, 3 269 are considered native species and 918 are introduced or nonnative.

Source: Condensed from Mosquin (1990).

Loss and potential loss of biological diversity

Loss and potential loss of Canada's biological diversity serve as useful indicators of ecological stress caused by human actions. Since Europeans began arriving in the early 1500s, 19 species or subspecies of animals have disappeared from Canada. Nine of them have become extinct, whereas remnant populations of the other 10 still occur elsewhere in the world. The sea mink, Passenger Pigeon, Great Auk, longjaw and deepwater ciscoes, and blue walleye were devastated by overharvesting before the advent of game laws. The black-footed ferret disappeared more recently as agricultural crops supplanted native vegetation and destroyed essential habitat. Indeed, habitat destruction now constitutes a much greater threat than overhunting to many wildlife species. The removal of living space, or its profound alteration by toxic contaminants, acidic deposition, and other environmental changes induced by human activity, has created conditions under which many species can no longer live and reproduce.

PRESSURES ON WILDLIFE

From the outset, Canada's economy has relied heavily on natural resources. At first, fortunes were amassed from the harvest of furs, whale oil, and fish. Later, timber, minerals, oil and gas, and grain fuelled the economic engine and, in the process, swallowed up vast amounts of wildlife habitat. Today, logging, mining, oil and gas development, and farming continue to exert increasing pressures on the ecosystems that sustain Canada's wildlife populations. A few examples of the principal pressures on various wildlife species in Canada are given in the following pages; the issue of habitat loss and degradation is addressed mainly in Chapter 26.

Agriculture

Of all human activities, agriculture has probably had the greatest effect, directly and indirectly, on wildlife. By clearing forests, replacing natural vegetation with crops, draining wetlands, and destabilizing natural biochemical balances by the use of chemical fertilizers, insecticides, and herbicides, agriculture has been responsible for dramatic reductions in the numbers and range of some species and the introduction of other species into new areas.

The Greater Prairie-Chicken, for example, has recently been extirpated from the Prairie provinces as a result of intensified cattle grazing and grain harvesting (Minish 1990). In Ontario, the moist, grassy, meadow habitat of the threatened Henslow's Sparrow has been reduced by intensive cultivation (Knapton 1984; McNicholl 1988). On the other hand, the Brown-headed Cowbird, originally found only on the grasslands of the Prairie provinces, has expanded eastward as far as the Maritimes in areas that have been cleared for crops (Cadman *et al.* 1987). This expansion in turn has influenced other native species. The Brown-headed Cowbird follows a parasitic strategy for reproduction, laying its eggs in the nests of Red-eyed Vireo, Yellow Warbler, Song Sparrow, and other songbirds and thereby reducing the host birds' chances of successfully raising their own young.

Among plant species, too, the impact of cultivation can be devastating. Once disrupted and replaced by cropland, many native plant communities are unable to reestablish themselves, even if the land is later withdrawn from active crop production. The original grasses and wildflowers, often suited to highly specialized ecological niches, tend to be supplanted by opportunistic weed species — some native, some imported.

Grazing by cattle and other domestic animals reduces plant cover and, hence, the supply of food and shelter for meadow and grassland species of mammals, birds, and invertebrates. Overgrazing leads to soil erosion and further degradation of habitat, especially during dry periods. Even heavy grazing, however, can benefit a few species. The endangered Mountain Plover, for example, prefers to nest on heavily grazed grassland, but not in areas with tall grass cover or shrubs (Wershler and Wallis 1987). Similarly, burning and other methods of reducing shrubs and tall grass may eliminate habitats for some kinds of wildlife but expand opportunities for species better adapted to life under more exposed conditions.

The planting of farm shelterbelts to combat wind erosion has substantially increased the amount of woodland habitat within the predominantly grassland Prairie Life Zone (McNicholl 1988). In consequence, species such as the Red-tailed Hawk, Mourning Dove, Western Kingbird, and American Crow have increased their ranges within this life zone.

Some species have benefited from increased feeding opportunities provided by agricultural crops. Ducks, geese, Sandhill Cranes, and other migratory birds feed on grain left in stubble fields in Canada and on wintering ranges in the United States. Robins and blackbirds may feed on crops such as fruit and corn.

Agriculture has had a serious impact on the quality and quantity of wetlands in the southern latitudes of Canada (see Chapter 26). Drainage of marshes and sloughs to create croplands has accounted for 85% of all losses of wetlands across the country (Keating 1987). Nearly 20% (12 of 62) of plants deemed to be endangered, threatened, or vulnerable in Canada are wetland species (E. Haber, Canadian Museum of Nature, personal communication). The loss of wetlands therefore imposes severe stresses on the remaining populations.

Another agricultural threat to Canada's wildlife has become apparent in recent years with the growing interest in commercial production of native and exotic game species for food. Animals that escape from game ranches may carry diseases or genetic characteristics that can contaminate wild populations. Swine brucellosis in reindeer from Alaska and the Mackenzie delta has spread in this way to barren-ground caribou and their predators (Broughton *et al.* 1970; Neiland 1975; Tessaro and Forbes 1986). Multiple outbreaks of bovine tuberculosis in western Canada among ranched wildlife led, in 1990, to widespread quarantining of game ranches and the destruction of hundreds of infected elk, mule deer, fallow deer, bison, and other ranched species.

Forestry

Canada's forest area covers approximately 453 million hectares, some 54% (244 million hectares) of which is considered to be commercially productive and therefore to require some degree of forest management (Forestry Canada 1991). From 1986 to 1988, an average of slightly more than 1 million hectares of forest were logged each year (Forestry Canada and Canadian Pulp and Paper Association 1990), and some areas have been cut three or even four times in the last 200 years. Logging, coupled with extensive losses caused by forest fires and insects each year (see Chapter 10), is steadily reducing the area covered by old-growth and mixed-growth forests in Canada. By replanting logged or burnt-over areas with seedlings of a single species, forest managers establish even-aged, monoculture tree farms that further limit the diversity of wildlife habitat. In addition, logging roads and hydroelectric lines provide increased access to wildlife habitat for hunters and others in motorized vehicles, increasing the opportunity for kills and the amount of disturbance to critical ranges (Stemp 1985).

The effects of forestry practices on wildlife vary in different regions of Canada. In British Columbia, for example, many species depend on old-growth forest, of which only about 8.8 million hectares, or 9% of the total area of the province, remain (Foster 1989). In 1986, of a total of 226 464 ha logged in British Columbia (Forestry Canada and Canadian Pulp and Paper Association 1990), about 79 000 ha (35%) was old-growth rain forest. These trees are being replaced by managed tree plantations of fast-growing, single species (Foster 1989). Fragmentation of old forests and their replacement with younger stands reduce the habitat available to the endangered Spotted Owl, the threatened Marbled Murrelet, and other wildlife species (British Columbia Ministry of Environment and Parks 1989). Less obvious practices, such as brush cutting, weeding, and herbicide spraying to accelerate the growth of evergreen plantations, reduce the supply of browse for moose, berries for black and grizzly bears, and nesting habitat for some bird species (British Columbia Ministry of Environment and Parks 1989).

In boreal forest regions, clear-cut logging tends to mimic the effects of forest fires by keeping large areas in the early successional stages of growth (Martell 1984). White-tailed deer, mule deer, moose, elk, Alder Flycatcher, and White-throated Sparrow often benefit from the shrubby regeneration that follows forest cutting. However, the pine marten, Golden-crowned Kinglet, Swainson's Thrush, and other species that prefer mature evergreen forests may decline. In contrast to the experience at uncut mature sites, marten populations in logged areas have been found to drop by 67–90% and to remain thus depressed for as long as 40 years after logging (Thompson 1988).

In the heavily populated areas of eastern Canada, fragmentation of the remaining forests by road construction, urban and industrial development, and agriculture is commonplace. One result is a reduction of woodland cover and an increase in "edge" habitat, where forests meet clearings. This benefits the Ruby-throated Hummingbird and other birds that favour mixed-woodland margins for nesting. It also benefits mice, squirrels, chipmunks, and other small mammals that find an abundance of nuts and fruit in these settings. Hares, rabbits, and deer also thrive in woodland margins where browse is plentiful. Throughout southern Ontario, Quebec, and Nova Scotia, however, the vulnerable southern flying squirrel has suffered from the loss and fragmentation of forest habitat and the removal of the old-growth, cavity-bearing trees that it needs for nesting and hibernation (Stabb 1988). Selective cutting, which is commonly practised in southern Ontario, removes mature trees, creates gaps in the forest canopy, and decreases the suitability of woodlots for Red-shouldered Hawks (Cadman 1989).

Traditionally, insofar as forest managers have considered wildlife conservation at all, they have viewed it from a relatively narrow perspective, focusing almost exclusively on species that are popular for hunting and trapping, such as deer, moose, elk, fur-bearing mammals, and Ruffed Grouse. In recent years, some resource managers have become more conscious of the ecological relationships that define a forest community and are considering the roles and needs of species with special habitat requirements, such as the pine marten and the Pileated Woodpecker, both of which need tree cavities for nesting or shelter. A heightened awareness of the importance of endangered, threatened, and vulnerable species may eventually lead to development of management prescriptions in aid of their survival and recovery (Quinlan *et al.* 1990).

Acidic deposition

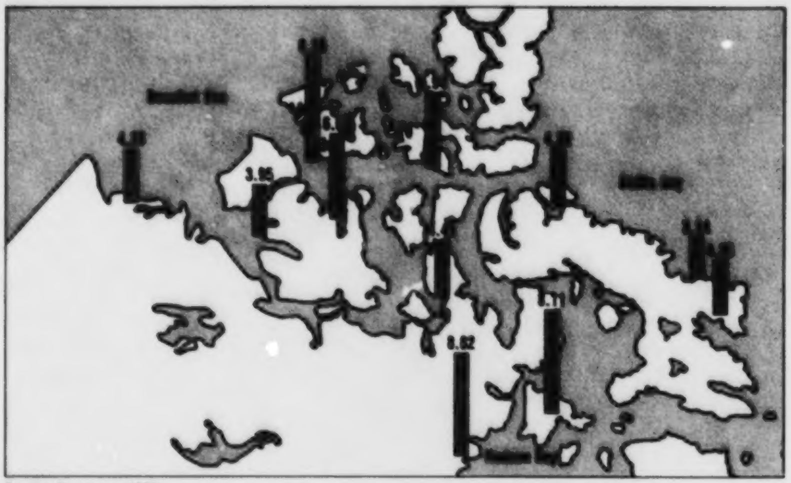
Acidic deposition, more commonly referred to as "acid rain" (see Chapter 24), introduces acidic pollutants, typically from distant sources, into terrestrial and aquatic habitats. The problem is particularly severe in eastern Canada, which lies downwind from major industrial centres in the United States and Canada. However, acidic deposition is really a nationwide problem. Even Yukon and the Northwest Territories receive measurable deposits of acidic pollutants from both North American and Eurasian sources.

By altering habitat, acidic pollutants have broad and serious effects on Canada's wildlife, both directly and indirectly. More than 60% of the country's land base has, at best, only a moderate ability to neutralize the acids (Environment Canada 1988). Chemicals are leached from the soil, depriving plants and animals of the nutrients that they require for normal growth. The transport of nutrients and water from roots to branches may be impaired, and even nitrogen-fixing soil bacteria can lose their effectiveness (Hirvonen 1989).

Wildlife in aquatic ecosystems is especially sensitive to acidic deposition. As water in rivers and lakes becomes more acidic, the eggs of aquatic organisms are less likely to hatch and mature. The species that are most sensitive to acidity, including many species of fish, insects, crustaceans, and molluscs, are eventually eliminated. The impoverished aquatic ecosystem that follows may be unable to supply the nutritional needs of waterfowl at breeding time, when calcium is required for the formation of eggshells and protein demands are high for growing chicks (RMCC 1990, part 4). Increased acidity also causes aluminum, cadmium, lead, and other potentially toxic metals to be more soluble and to be "mobilized" into the water. Methylmercury in fish from acidic lakes may reach concentrations that can interfere with reproduction in mink, loons, and other predators (Scheuhammer 1991). Cadmium is taken up by vascular plants and then accumulates in the livers and kidneys of herbivores such as moose and caribou, at levels that pose a risk to human consumers (RMCC 1990, part 5).

The threshold level of acidic sulphate deposition above which biological damage occurs in aquatic habitats has been determined to be less than 20 kg/ha per year for most of eastern [illegible] 6.1

PCB concentrations (in parts per million) in polar bear fat in the Canadian Arctic, 1982–84



Source: Norstrom (1990).

Canada and less than 8 kg/ha per year for the Atlantic provinces, where the soils and waters are particularly sensitive (RMCC 1990, part 4). Levels of sulphate deposition in most of southeastern Canada exceed these thresholds, resulting in reduced biological diversity — fewer species — in thousands of lakes and streams. For example, more than 55 000 lakes in eastern Canada have probably lost at least 20% of their potential species complement (Minns *et al.* 1990); fish and molluscs, in particular, are severely affected. Historical records for streams in Ontario's Algonquin Park have documented the loss of several acid-sensitive species of mayflies and stoneflies (Hall and Ide 1987). On a more optimistic note, reduction of emissions has been shown to lead to a gradual recovery of lake ecosystems (Schindler 1988).

Acidic pollutants have been implicated in a decline in the health of sugar maples in Quebec and Ontario, probably, in large measure, because of the loss of key nutrients from the soil. That decline, in turn, has meant a loss of habitat for the Least Flycatcher and other birds that forage in the canopy of mature deciduous forests (RMCC 1990, part 5). A rapid decline of white birch along the Bay of Fundy in New Brunswick is also attributed to acidic deposition.

Toxic contaminants

Toxic contaminants can have significant effects on the entire range of wildlife, from the smallest of microorganisms to the largest of plants and vertebrate animals. Instances of reproductive failure, congenital abnormality, physiological and behavioural alterations, and death have all been linked to the presence of toxic substances in the environment. The solubility of many toxic contaminants in animal fats, coupled with biomagnification of these substances up the food chain, makes many mammals, birds, and fish especially vulnerable.

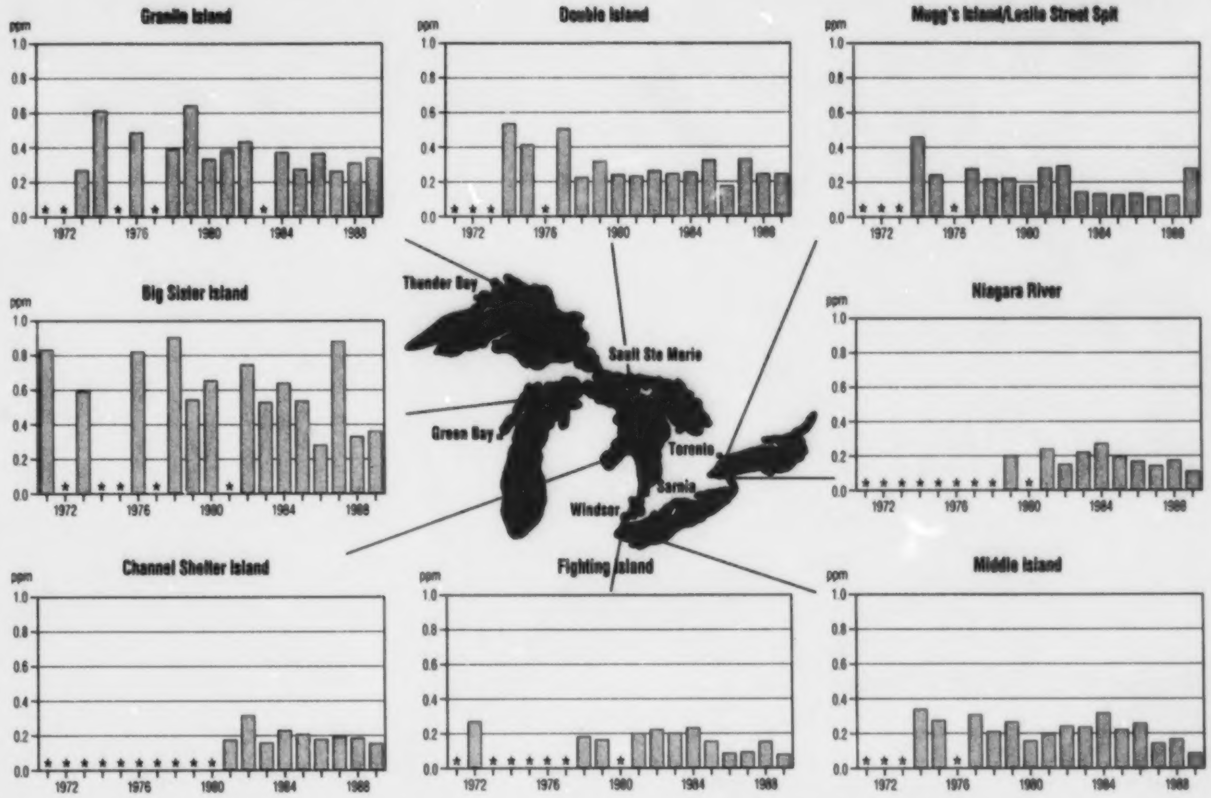
Toxic contaminants can be divided into two broad classes: those that enter the environment as incidental by-products of industrial manufacturing processes, and those, such as pesticides and fertilizers, that are produced and applied intentionally. Thousands of toxic contaminants are known; unfortunately, only a few have been studied to determine their effects on wildlife. Some of the insights that scientists have gathered are discussed below.

Monitoring of contaminants in seabird eggs indicates that levels of DDT and its derivatives have declined significantly in most inshore marine ecosystems since the early 1970s (Noble and Elliott 1986). Levels continue to be high in the St. Lawrence River estuary, however, because of industrial wastes, mobilization of pollutants from sediments and soil, municipal sewage, agricultural chemicals, and atmospheric deposition into the Great Lakes and St. Lawrence River. Levels of PCBs have also declined in most sampled locations, although not in the St. Lawrence estuary or off western Vancouver Island.

When compared with more southerly areas, marine ecosystems in Canada's Arctic do not generally suffer from severe contamination. For example, levels of PCBs and DDT in Arctic-dwelling ringed seals and beluga are 10–50 times lower than in the same species at mid-latitudes in Canada and Scandinavia. On the other hand, not even arctic species are wholly exempt from the toxic by-products of human activity. Levels of total PCBs in polar bear fat samples tested in 1982–84 were roughly in the 3–8 ppm range (Fig. 6.1). Chlordane compounds in fat and liver were in the 2–8 ppm range. The effects of these substances on the bears are still unknown. However, polar bear fetuses and cubs are probably at greater risk from the toxic effects of chlorinated organics than older bears, because of the high concentrations mobilized from the mother bear's fat in the den over the winter and transferred to the young through the placenta and through milk after birth (Norstrom 1990). The fact that PCBs and chlordane compounds were found in all areas sampled indicates that long-range transport of chlorinated organics from distant sources is mainly responsible for the contamination of arctic marine ecosystems (see Chapter 15). As well, levels of dioxins in polar bears and ringed seals in the central Arctic exceed those found in wildlife in more southerly parts of Canada — strong evidence that the contaminants originated outside North America (Twitchell 1991).

[illegible]

Trends in average annual concentration of dieldrin in Herring Gull eggs at eight colonies on the Great Lakes



*Indicates no data.

Source: Bishop and Weseloh (1990).

Levels of contaminants in the Great Lakes have been monitored since 1968. Levels of almost all chlorinated organics measured, such as dieldrin levels in Herring Gull eggs, have generally decreased since the early to mid-1970s (Fig. 6.2; see also Chapter 18). However, current concentrations of some contaminants are believed to be still sufficient to cause reproductive problems and congenital defects. Such effects are now seen only in a few remaining areas where local sources of contamination still exist (K.M. Lloyd, Environment Canada, Canadian Wildlife Service, personal communication). Populations of several species of birds of prey collapsed between 1946 and 1971 because of reproductive impairment from chlorinated organic pesticides. Most now appear to be stable or recovering, with possible exceptions, such as the Red-shouldered Hawk (Bednarz *et al.* 1990).

High levels of dioxins and furans have recently been found in the eggs of Great Blue Herons (Elliott *et al.* 1989) and cormorants (Whitehead *et al.* 1989), in the livers of fish-eating waterfowl (Whitehead *et al.* 1990), and in samples of fish, molluscs, and crustaceans near kraft pulp mills in British Columbia. At a Great Blue Heron colony near Vancouver, levels of various dioxins were found to be 3–10 times higher in 1989 than in 1982–86 (Whitehead *et al.* 1989). These contaminants are believed to originate in the chlorine bleaching process used at pulp and paper mills and from chlorophenol wood treatment chemicals used in sawmill operations. Dioxins are highly toxic to bird embryos. Studies have linked high dioxin levels in Great Blue Heron embryos to sublethal effects that include reduced body weight, edema, and induction of liver enzymes (Bellward *et al.* 1990; Hart *et al.* 1991). Dioxins may be partly responsible for the reproductive failure that occurred, in 1987, at a Great Blue Heron colony near a kraft pulp mill at Crofton, B.C. (Elliott *et al.* 1989).

More than 30 registered pesticides, including diazinon, carbofuran, and fenitrothion, have been known to kill wild birds and mammals, even when used according to instructions. Organophosphate and carbamate insecticides, which affect the nervous system of insects and vertebrates alike, cause the most deaths. Direct poisonings occur when geese and other grazing species ingest pesticide-contaminated vegetation or when small seed-eating species mistake insecticide granules for seed or grit (Mineau 1988). One granule of carbofuran, for example, can kill a Lapland Longspur, and migrating flocks of hundreds of these birds may land in treated fields. Birds of forest and field can be affected by sprayed insecticides, which may be ingested, inhaled, or absorbed through the skin (Mineau and Peakall 1987). Amphibians may also be exposed to pesticides in both terrestrial and aquatic ecosystems. Secondary poisoning may strike predators that ingest contaminated prey. For example, Bald Eagles and various hawks have died after eating birds and mammals that had been killed by ingestion of granular carbofuran. Strychnine used to kill wolves and coyotes has also killed Golden Eagles, Common Ravens, foxes, and other scavengers. Anticoagulant rodenticides, such as brodifacoum, also kill raptors that feed upon dead or dying prey. Similarly, fenthion used to kill House Sparrows and Rock Doves (domestic pigeons) has also killed predators of the contaminated birds (Hunt *et al.* 1991*a*, 1991*b*). Sublethal effects of pesticides include aberrant behaviour, loss of coordination and appetite, reproductive failure, and general impairment of health. Breeding birds may spend less time at the nest, fail to provide sufficient food for their young, be less able to escape predators, and be more aggressive with their mates.

Even biological control agents may have undesirable effects. For example, the biological insecticide *Bacillus thuringiensis* is more target specific to gypsy moth and spruce budworm than the chemical alternatives, but it still affects all moth and butterfly species. Deltamethrin, fenvalerate, and other pyrethroid insecticides applied to a wetland can decimate the aquatic invertebrates that sustain young waterfowl and other wildlife (Mineau *et al.* 1987).

Herbicides that are applied to kill unwanted plants may affect other wildlife by eliminating sources of food or shelter. For example, many weeds that are targeted for control in agricultural areas are important food sources for birds. Herbicides can also destroy nesting cover for duck species that lay their eggs in the shelter of hedgerows and field margins. It has been estimated that this practice could reduce by close to 20% nesting success by ducks that use this type of nest site in prairie and parkland areas (Sheehan *et al.* 1987). Endangered, threatened, or vulnerable plants can also be killed by the indiscriminate use of common herbicides, as can aquatic vegetation and invertebrates in wetlands that receive runoff from treated areas.

Oil spills continue to threaten marine and freshwater life. Chronic pollution from frequent minor spills can be just as hazardous to wildlife as large spills that occur rarely (R.G.B. Brown, Environment Canada, Canadian Wildlife Service, personal communication). For example, the release of about 8 000 t of oil from the wrecked tanker *Arrow* off the coast of Nova Scotia in 1970 resulted in the death of an estimated 7 200 birds; a spill of only 30 t from the barge *Irving Whale* off Newfoundland in the same year killed at least 5 000 birds.

Intentional discharges of ballast water from oil tankers and other ships at sea account for a significant portion of all oil entering marine waters. They are a major cause of wildlife deaths. Murres, puffins, fulmars, shearwaters, and other seabirds are greatly at risk from oiling, as are sea otters (Brown 1982). Oil breaks down the waterproofing and insulating qualities of feathers and of fur. It is also harmful when ingested, whether in the course of preening oiled feathers or fur, feeding on oiled seaweeds, or, in the case of predators and scavengers, eating contaminated prey or carrion. Seabirds are most vulnerable at breeding colonies and feeding areas where they concentrate. The risk is similar in freshwater areas that support large populations of waterfowl and other wildlife, such as Cap Tourmente, in the St. Lawrence River estuary, and lakes Erie and St. Clair.

Lead poisoning of waterfowl has been documented in North America since the late 1880s. Feeding waterfowl often ingest spent lead shotgun pellets that have settled into wetland sediments. The ingested pellets, rather than passing directly through the digestive system, are often retained for days in the gizzard to assist in grinding up food. As a result, lead is absorbed into the bloodstream. Lead poisoning has been identified as a particular danger to waterfowl in marshes adjacent to Lake St. Clair in southwestern Ontario, for Canada Geese in Oak Hammock Marsh in Manitoba, and for Trumpeter Swans and Bald Eagles (via prey species) in British Columbia. Since 1990, nontoxic steel shot has been required along a segment of the eastern perimeter of Lake St. Clair, in southern portions of Vancouver Island, and in southern portions of mainland British Columbia.

Introduced species

Thousands of species of plants and animals from around the world have been introduced, accidentally or intentionally, into Canada. Many occupy artificially created habitats to which few or no native species are adapted. Others, however, have caused severe economic and ecological damage. Over 500 species of introduced plants have become agricultural "weeds" (Crompton *et al.* 1988) that cause significant economic losses by competing with agricultural crops. The European Starling, introduced to North America in 1890, has prospered, spreading in great numbers across southern Canada and competing for nest sites to the detriment of less aggressive native species, such as the Eastern Bluebird. Some ecologists fear that exotic mammals on Canadian game ranches may escape, threatening native species with disease, hybridization, and competition, as has happened recently in the western United States (Lanka *et al.* 1990).

Despite increasingly stringent national and international laws regulating the introduction of exotic species, the list is growing. The tiny zebra mussel, now wreaking havoc in the Great Lakes, provides a striking example of how serious such introductions can be (see Box 18.2). This tiny European mollusc was introduced into Lake St. Clair from water dumped from a ship's ballast tanks (Banks 1990), probably in 1985. Because the mussels filter plankton from vast quantities of water, they deny huge quantities of food to fish larvae and thus imperil walleye, bass, perch, and other fish, as well as fish-eating wildlife species further up the food chain.

Climatic change

Fossil fuel combustion and the widespread removal of forest cover around the world are two reasons for large increases in the amount of carbon dioxide in the atmosphere. Methane, nitrous oxide, chlorofluorocarbons, and ground-level ozone are also increasing. Higher concentrations of these gases are augmenting what is commonly referred to as the "greenhouse effect" (see Chapter 22 for detail on the mechanisms of this phenomenon). The Intergovernmental Panel on Climate Change (1990) predicts an average rate of increase of global mean temperature of about 0.3°C per decade during the next century, based on modelling results using current emissions of greenhouse gases.

The impact of global warming on Canada's biological diversity is likely to be immense, especially through alterations to wildlife habitat (see Chapter 26). At the predicted rate of global warming, drastic changes could occur within a human life span (Zoltai 1988). For example, expansion of ocean waters due to increased temperatures and the melting of glaciers, ice caps, and sea ice in the high Arctic may raise mean global sea levels by about 6 cm per decade, flooding coastal wetlands and beaches and rendering them unusable for feeding and brood-rearing by shorebirds and waterfowl. Melting of the arctic sea ice may also have catastrophic impacts on polar bear, walrus, and seals, which rely heavily on sea ice for resting, feeding, and breeding sites.

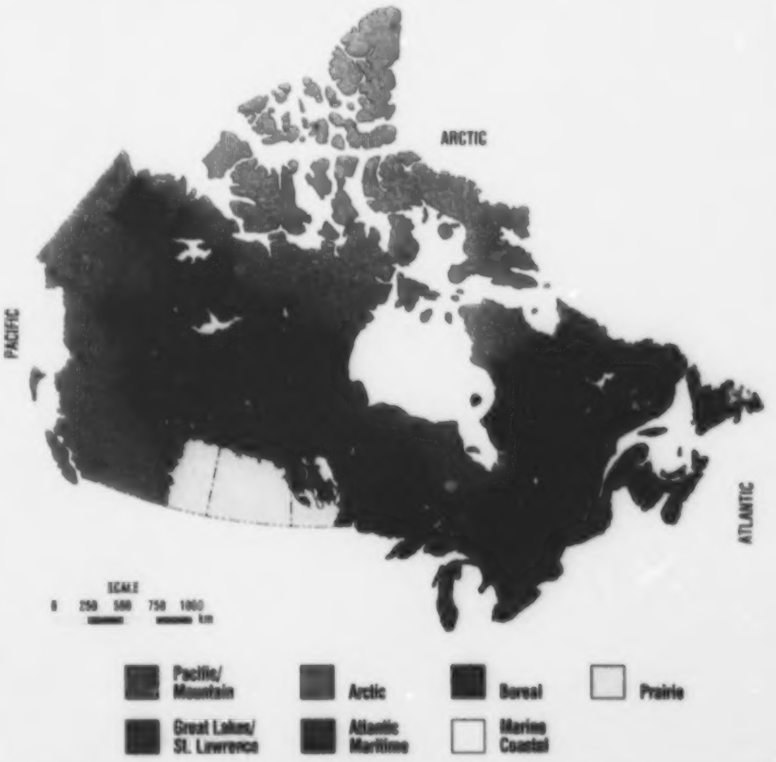
Some experts warn that global warming may be proceeding at a rate 10–40 times faster than the cooling that occurred during the Wisconsin glaciation. That cooling period was marked by major shifts in ecological conditions, and at least 32 genera of mammals became extinct (Cubberley 1989). The precise effects of global warming on particular species are still unclear, but the broader implications are evident. Those species least tolerant of ecological change and those least able to reproduce quickly and spread into new areas will probably be most susceptible.

WILDLIFE TRENDS IN CANADA'S LIFE ZONES

Subjected as it is to numerous and sometimes severe pressures, how is wildlife faring in Canada? This section focuses on the condition of wildlife and trends in wildlife populations within a geographic framework of seven life zones (Fig. 6.3). These zones generally reflect the terrestrial ecozones of Canada (Wiken 1986; see also Chapter 5). They are broad landscapes and marine ecosystems that are relatively familiar to most Canadians. The principal physical, biological, and land-use characteristics and some communities for each life zone of Canada are highlighted in Table 5.1 by descriptions of the ecozones of which they are composed (Table 6.2).

FIGURE 6.3

Life zones of Canada



Source: Burnett *et al.* (1989).

TABLE 6.2

How the seven life zones correspond to the terrestrial ecozones of Canada

Life zone	Terrestrial ecozone(s) included
Pacific/Mountain	Tundra Cordillera, Boreal Cordillera, Pacific Maritime, and Montane Cordillera
Arctic	Southern Arctic, Northern Arctic, Arctic Cordillera, and Hudson Plains
Boreal	Boreal Plains, Taiga Plains, Taiga Shield, and Boreal Shield
Prairie	Prairie
Great Lakes/St. Lawrence	Mixed Wood Plains
Atlantic Maritime	Atlantic Maritime
Marine Coastal	Not applicable: encompasses marine environments of the Pacific, Arctic, and Atlantic oceans

BOX 6.1

The Banff longnose dace: a species lost forever

Mention extinction and many Canadians will assume that you are talking about a prehistoric event, despite the fact that the Earth is experiencing a rapid and serious loss of species right now, in the closing years of the 20th century. Although the process is global and continuous, we tend not to associate extinction with our own lives and times, and least of all as something that could happen within the boundaries of a national park. Nevertheless, wildlife species can indeed be lost in unlikely ways, as the following story demonstrates.

The Banff longnose dace, a small Alberta minnow, inhabited only one place in the entire world — a marsh fed by warm waters from the Cave and Basin hotsprings in Banff National Park. It was first discovered and described there in 1892, at a time when it was said to be abundant, and specimens continued to be collected for study as late as 1981. By then, however, the diminishing number of fish being taken indicated that the population was falling, and scientific collecting may itself have been partly responsible (Lanteigne 1988).

Another factor that may have contributed to the decline is the fact that, over the years, guppies, swordtails, sailfin mollies, and other species of tropical fish had been released into the marsh, where the warm waters accelerated their rate of growth. Competition by these exotics for food and direct predation on dace eggs were two limiting influences on the sustainability of the rare fish (McAllister *et al.* 1985). There were also indications of hybridization between the remnant population of Banff longnose dace and another, more common dace subspecies.

However, it appears that a human hygienic practice may have been the last straw. In the mid-1980s, a proposal was approved, for the first time, to chlorinate the hotspring water used to fill the swimming pool at a nearby resort hotel. Most of the free chlorine would be driven off while the water was in the pool, posing little or no threat. However, the remainder reacted with organic wastes to form chlorinated hydrocarbons and chloramines, which can be toxic to fish at relatively low doses. In April 1987, the members of the Committee on the Status of Endangered Wildlife in Canada declared the Banff longnose dace to be extinct (Campbell 1988). One more fragment of the world's biological diversity was lost forever.

Wildlife conditions and trends within each life zone serve as indicators of overall environmental health. One indicator of problems with respect to environmental well-being of any particular area is the occurrence of species at risk. Table 6.3 summarizes the current status of endangered and threatened species, subspecies, and populations in Canada and indicates the life zone in which each occurs. Nearly half the endangered and threatened species in the country occur in the Great Lakes/St. Lawrence Life Zone (Table 6.4).

Pacific/Mountain Life Zone

The Pacific/Mountain Life Zone is the most biologically diverse in Canada. Two endangered species, the Vancouver Island marmot and the Enos Lake stickleback, are endemic to this life zone — i.e., not found anywhere else. The population of the Vancouver Island marmot is estimated to be about 300 individuals (British Columbia Ministry of Environment and Parks 1989), up from 234 in 1984 (Munro *et al.* 1985).

About 16 000 grizzly bears, 80% of the total Canadian population of 20 000, live in British Columbia and Yukon. The rest are found in Alberta and the Northwest Territories (Macey 1979). The British Columbia grizzly bear population is reportedly stable or decreasing (British Columbia Ministry of Environment and Parks 1989), but some environmental groups feel that an estimate of 12 500 bears in the province is an exaggeration. Grizzly bears do not adapt well to human activity. As a result, local populations continue to be vulnerable to the expansion of forest and mineral resource development and to an increased human presence in remote areas (British Columbia Ministry of Environment and Parks 1989).

Most ungulates appear to be faring well in the Pacific/Mountain Life Zone, with increasing numbers of mule deer (135 000) and Rocky Mountain elk (35 000) and stable to increasing populations of Rocky Mountain bighorn sheep (2 500), California bighorn sheep (3 000), Dall's sheep (500), and Stone's sheep (11 500). Herds of mountain caribou in British Columbia are considered to be stable, with a cumulative total of about 13 500 animals, but the long-term survival of healthy populations in the central and southeastern parts of the province will require protection of sufficient old-growth forest habitat (British Columbia Ministry of

Current status and life zones of endangered and threatened species, subspecies, and populations in Canada

Species group	Status and life zone[a]	
	Endangered[b]	**Threatened[b]**
Mammals	Beluga (white whale) • southeastern Baffin Island pop. **A**, **MC** • St. Lawrence River pop. **GL** • Ungava Bay pop. **MC** Bowhead whale **MC** Eastern cougar **AM**, **B**, **GL** Peary caribou • Banks Island pop. **A** • high-arctic pop. **A** Right whale **MC** Sea otter **MC** Vancouver Island marmot **PM** Wolverine (eastern pop.) **B**, **A**	Beluga (eastern Hudson Bay pop.) **A**, **MC** Harbour porpoise (western Atlantic pop.) **MC** Humpback whale (North Pacific pop.) **MC** Newfoundland pine marten **B** Peary caribou (low-arctic pop.) **A** Prairie long-tailed weasel **P** Wood bison **B** Woodland caribou (Maritime pop.) **AM**
Birds	Eskimo Curlew **A** Harlequin Duck (eastern pop.) **AM**, **MC** Kirtland's Warbler **GL** Loggerhead Shrike (eastern pop.) **GL** Mountain Plover **P** Peregrine Falcon, subspecies *anatum* **B**, **GL**, **AM** Piping Plover **P**, **GL**, **AM** Spotted Owl **PM** Whooping Crane **B**	Baird's Sparrow **P** Burrowing Owl **P** Ferruginous Hawk **P** Henslow's Sparrow **GL** Loggerhead Shrike (prairie pop.) **P** Marbled Murrelet **PM**, **MC** Peregrine Falcon, subspecies *tundrius* **A** Roseate Tern **AM**
Fish	Acadian whitefish **AM** Aurora trout **B** Salish sucker **PM**	Black redhorse **GL** Blackfin cisco **GL** Copper redhorse **GL** Enos Lake stickleback **PM** Great Lakes deepwater sculpin **GL** Lake Simcoe whitefish **GL** Margined madtom **GL** Shorthead sculpin **PM** Shortjaw cisco **B**, **GL** Shortnose cisco **GL**
Amphibians and reptiles	Blanchard's cricket frog **GL** Blue racer **GL** Lake Erie water snake **GL** Leatherback (turtle) **MC**	Eastern massasauga **GL** Eastern spiny softshell **GL**
Plants	Cucumber tree **GL** Eastern mountain avens **AM** Eastern prickly pear cactus **GL** Furbish's lousewort **AM** Gattinger's agalinis **GL** Heart-leaved plantain **GL** Hoary mountain mint **GL** Large whorled pogonia **GL** Pink coreopsis **AM** Pink milkwort **GL** Skinner's agalinis **GL** Slender bush clover **GL** Small white lady's slipper **P**, **GL** Small whorled pogonia **GL** Southern maidenhair fern **PM** Spotted wintergreen **GL** Thread-leaved sundew **AM** Water-pennywort **AM** White prairie gentian **GL**	American chestnut **GL** American water-willow **GL** Anticosti aster **AM** Athabasca thrift **B** Bird's foot violet **GL** Blue ash **GL** Bluehearts **GL** Colicroot **GL** Giant helleborine **PM** Ginseng **GL** Golden crest **AM** Golden seal **GL** Kentucky coffee tree **GL** Mosquito fern **PM** Nodding pogonia **GL** Pitcher's thistle **GL** Plymouth gentian **AM** Purple twayblade **GL** Red mulberry **GL** Sweet pepperbush **AM** Tyrrell's willow **B** Western blue flag **P**

[a] **PM** Pacific/Mountain
A Arctic
B Boreal
P Prairie
GL Great Lakes/St. Lawrence
AM Atlantic Maritime
MC Marine Coastal

[b] Defined in the Glossary.

Source: Compiled by C. Dauphiné, Environment Canada, Canadian Wildlife Service.

Number of endangered and threatened species, subspecies, and populations in each of Canada's life zones

Life zone	Number	% of total number in Canada
Pacific/Mountain	9	9.4
Arctic	8	8.3
Boreal	10	10.4
Prairie	9	9.4
Great Lakes/St. Lawrence	46	47.9
Atlantic Maritime	16	16.7
Marine Coastal	11	11.5
Total number in Canada	**96[a]**	

[a] The sum of the number of species, subspecies, and populations in each life zone exceeds the total number in Canada because some species are found in more than one life zone.

Source: C. Dauphiné, Environment Canada, Canadian Wildlife Service, personal communication.

Environment and Parks 1989). The Porcupine herd of barren-ground caribou, which ranges mainly in Yukon and Alaska and calves in the Arctic Life Zone, has shown a healthy average annual rate of increase of 5% since 1983, numbering about 178 000 in 1989 (Porcupine Caribou Management Board 1990). This herd may, however, be at risk from proposed oil development in the Alaska Arctic National Wildlife Refuge.

The Ancient Murrelet, a burrow-nesting seabird, has declined in numbers at several colonies in the Queen Charlotte Islands, where rats and other introduced predators appear to be at the root of the problem. Populations of other burrow-nesting seabirds appear to be stable or increasing, with an estimated 2.2 million Cassin's Auklets (A.J. Gaston, Environment Canada, Canadian Wildlife Service, personal communication) and 446 000 breeding Rhinoceros Auklets (British Columbia Ministry of Environment and Parks 1989).

The Salish sucker has been designated as endangered because of habitat changes and declining water quality associated with urbanization. Its Canadian range now appears to be

TABLE 6.4

Some population trends and conditions of Canadian wildlife, by life zone

Life zone	Species, subspecies, or population	Status as per COSEWIC[a]	Estimated population	Recent trend	Principal pressures or limitations	Notes	Reference(s)
Pacific/Mountain	•Keen's long-eared bat	•vulnerable	•unknown	•probably declining	•habitat loss	•appears to be restricted to dense, old-growth forest	•Balcombe (1988)
	•Cougar	•not listed	•3 000 in British Columbia	•stable or increasing	•hunting, habitat loss, human disturbance	•cougar extirpated or greatly reduced over most of its former range	•British Columbia Ministry of Environment and Parks (1989)
	•River otter	•not listed	•15 000 – 30 000 in coastal B.C., unknown in interior B.C.	•stable, thought to be declining	•loss of riparian habitat to development, water pollution		•British Columbia Ministry of Environment and Parks (1989)
	•Bald Eagle	•not listed	•15 000 adult birds in British Columbia	•stable	•habitat loss	•depends on large, old-growth trees for nesting and roosting	•British Columbia Ministry of Environment and Parks (1989)
	•Marbled Murrelet	•threatened	•45 000 breeding birds	•stable or declining	•habitat loss	•nests in old-growth forest, first occupied nest of this secretive bird in Canada discovered in B.C. in 1990	•Rodway (1990)
	•Western rattlesnake	•not listed	•10 000	•probably declining	•habitat loss, commercial exploitation for pet trade	•found in south-central B.C.	•British Columbia Ministry of Environment and Parks (1989)
Arctic	•Barren-ground caribou	•not listed		•herds increasing or stable during the 1980s		•calve and summer in the Arctic Life Zone	
	– Kaminuriak herd		•114 000 – 296 000				
	– Beverly herd		•115 000 – 263 000				
	•Polar bear	•vulnerable	•more than 10 000	•stable	•hunting (in 1988–89, 609 killed, mostly by hunting), toxic contaminants (levels in bears increasing in recent years)	•harvest levels generally in balance with the population, toxic contaminants bioaccumulating and biomagnifying in the food chain (see Chapter 15)	
Boreal	•"Tundra" caribou	•not listed			•hunting, hydroelectric developments		
	–George River herd		•682 000	•stable		•historic high in late 1980s	•Crête *et al.* (1989)
	–Leaf River herd		•100 000	•stable			•Crête *et al.* (1987)
	•Newfoundland pine marten	•threatened	•630–875	•unknown	•loss of old-growth evergreen forest		•Snyder (1990)
	•Aurora trout	•endangered	•unknown pop. in the wild	•unknown	•acidic deposition	•species sustained only by captive breeding and reintroduction to suitable lakes	•Parker and Brousseau (1987)
Prairie	•Burrowing Owl	•threatened	•3 000 in Sask., 2 000 in Alta., 56 in Man., 8 in B.C.	•declining	•habitat loss, insecticide poisoning		•Burrowing Owl Recovery Team (1989)
	•Long-billed Curlew	•not listed	•5 000 – 8 500 in Alta. and Sask.	•declining	•loss and fragmentation of breeding habitat		•De Smet (1989)
	•Piping Plover	•endangered	•2 000 in Canada		•habitat loss and agricultural practices	•three-quarters of Canadian population in this life zone	•Burnett *et al.* (1989)
Great Lakes/ St. Lawrence	•Peregrine Falcon, subspecies *anatum*	•endangered	•14 breeding pairs in Que., 2 in Ont.	•slight increase	•toxic contaminants	•reintroduced to the St. Lawrence River valley	•G. Holroyd, Environment Canada, Canadian Wildlife Service, personal communication
	•Double-crested Cormorant	•not listed	•unknown	•increasing	•toxic contaminants	•severe declines in 1960s, 1970s due to chlorinated organics; pop. recovering as contaminant levels decrease	
	•Common Tern	•not listed	•unknown	•recent declines	•competition from Ring-billed Gulls		•Blokpoel and Harfenist (1986)

Life zone	Species, subspecies, or population	Status as per COSEWIC[a]	Estimated population	Recent trend	Principal pressures or limitations	Notes	Reference(s)
Atlantic Maritime	•Roseate Tern	•threatened	•100–130 breeding pairs	•declining	•competition with and predation from gulls	•marked decrease in north-eastern N.A. over the last 100 years	•Burnett *et al.* (1989)
	•Common Eider	•not listed	•unknown but nearly extirpated from Newfoundland	•declining	•hunting	•being reestablished in Newfoundland with eggs from Quebec	
Marine Coastal	•Beluga (St. Lawrence River pop.)	•endangered	•400 (1990)	•declining	•toxic contaminants (including PCBs), habitat loss	•remaining individuals so heavily contaminated that reproduction may be impaired	•MacLeod (1990)
	•Gray whale (northeastern Pacific pop.)	•no longer considered to be at risk	•15 000	•stable or increasing	•centuries of commercial harvesting	•still harvested to a limited extent	•Reeves and Mitchell (1987)
	•Sea otter	•endangered	•>370	•stable or increasing	•centuries of commercial harvesting	•breeds at only 2 sites, 89 individuals transplanted from Alaska, 1969–72	•Macaskie (1986); British Columbia Ministry of Environment and Parks (1989)
	•Narwhal (eastern Arctic)	•not listed	•>18 000	•stable	•hunting	•subject to traditional hunt of about 500 animals annually	•Strong (1987)
	•Thick-billed Murre (Arctic)	•not listed	•2 600 000 breeding adults	•stable or increasing			•Nettleship and Evans (1985); A.J. Gaston, Environment Canada, Canadian Wildlife Service, personal communication
	•Common Murre	•not listed	•1 200 000 breeding birds (95% of North American population)	•stable	•significant losses in fish nets and due to oil spills	•concentrated at a few large colonies on Newfoundland	•Nettleship and Evans (1985)

[a] Committee on the Status of Endangered Wildlife in Canada.

restricted to a few streams in the southwest corner of mainland British Columbia (McPhail 1986). Another fish species of this life zone, the Banff longnose dace, in 1987 was declared to be extinct (see Box 6.1, page 6–12).

Clouded salamander populations are diminishing as the availability of rotting wood in Douglas-fir forests, their favoured habitat, is reduced by such forestry practices as the removal of decaying trees and logs and the loosening of topsoil in preparation for tree planting (British Columbia Ministry of Environment and Parks 1989). Information on other selected species in the Pacific/Mountain Life Zone is summarized in Table 6.5.

Arctic Life Zone

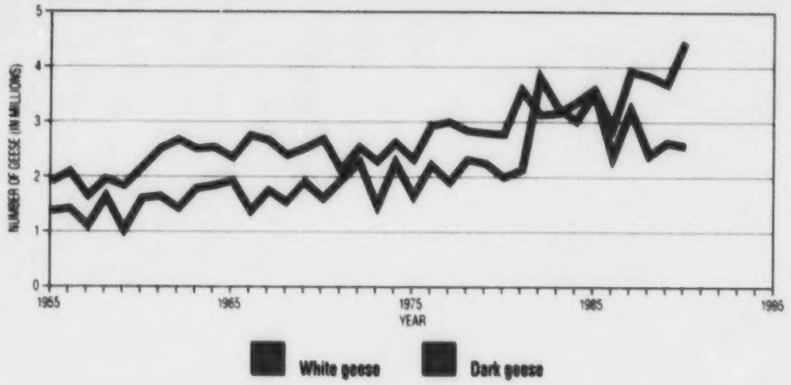
The Arctic Life Zone, which extends beyond the northern tree line, has two endangered species: the Eskimo Curlew and the Banks Island and high-arctic populations of the Peary caribou. As early as 1900, numbers of the Eskimo Curlew had been decimated by unrestricted hunting during spring and fall migrations, possibly augmented by habitat loss and severe climatic stresses. Today, fewer than 20 birds are thought to remain (Gollop and Shier 1978), but efforts continue in the hope of locating and restoring breeding populations (Eskimo Curlew Advisory Group 1990). Since the early 1960s, the high-arctic population of the Peary caribou, on the Queen Elizabeth Islands, has declined by about 90% to between 3 300 and 3 600 animals, and in 1991 this population was declared endangered. In this instance of drastic decline, the main problem appears to be extreme malnutrition due to a lack of available forage during unusually harsh winters (Miller 1990). The Banks Island population, also designated endangered, has declined since the early 1970s to an estimated 2 660 in 1989 (less than 30% of its former size), seemingly from the combined effects of severe winters and hunting pressure (Miller 1990).

The Canadian Arctic is the primary breeding ground in the western hemisphere for plovers, sandpipers, turnstones, and many other shorebirds. Most of these species undertake extremely long annual migrations between their breeding grounds in the Arctic and wintering areas far to the south. Of the 49 shorebird species that breed in Canada's Arctic, 36 winter in Latin America, where large tracts of wetland and grassland habitat have disappeared or are threatened by human activities (Morrison and Ross 1989). Long-term data for 12 species of shorebirds at migration sites in eastern North America indicate that populations of Whimbrels, Short-billed Dowitchers, and Sanderlings declined significantly from 1972 to 1983. Indeed, all but 2 of the 12 species showed an overall decline during the period (Howe *et al.* 1989).

The Arctic also provides breeding grounds for several species of geese, including the Greater Snow Goose,

[illegible]

Trends in the numbers of white[a] and dark[b] geese in wintering areas in the United States



[a] Snow Goose, Ross's Goose.

[b] Canada Goose, White-fronted Goose, Brant.

Source: Environment Canada (1990).

the Lesser Snow Goose, and the familiar Canada Goose. Observations in their wintering areas suggest that populations of geese breeding in the Arctic have tended to increase since 1955 (Fig. 6.4). Their breeding habitats have been affected very little by human activities, and the establishment of ecological reserves and improved wintering grounds has favoured population growth. Trends for some other species in the Arctic Life Zone are shown in Table 6.5.

Boreal Life Zone

The forest cover of the Boreal Life Zone is largely evergreen, although birch, poplar, and other deciduous trees are interspersed with the dominant spruces, firs, and pines. Considering its vast area, this life zone displays relatively little biological diversity, although some individual species, including blackflies, mosquitoes, and other biting flies, are remarkably abundant (Danks 1988). In the past two decades, the Boreal Life Zone has experienced major human interventions, notably in the form of large-scale forestry, mining, and hydroelectric developments. Megaprojects such as the James Bay power project in Quebec have altered large areas of terrestrial and aquatic habitat (Gorrie 1990). Such developments can profoundly change not only the species composition and populations of wildlife in these areas, but the condition of the aboriginal human inhabitants as well, disrupting traditional lifestyles and posing potential health problems.

Canada's best-known endangered species, the Whooping Crane, breeds in the Boreal Life Zone. Recovering from a low of 21 birds in 1940, the wild flock now numbers about 134 and is relatively secure on its breeding grounds within Wood Buffalo National Park. However, during migration and on wintering grounds on the Gulf coast of Texas, predators, oil slicks, and other hazards pose serious threats to the cranes' survival. As the birds commenced their northward journey in spring 1991, observers reported that 12 of the 146 birds that had arrived the previous fall were missing. One is known to have been shot, and feathers and bones of a second were found, but the other 10 seem to have vanished without a trace.

The wood bison of the boreal zone was always less numerous than its more southerly grassland counterpart, the plains bison. However, for largely unknown reasons, once-healthy populations had declined to a low of several hundred animals in the 1890s. Hybridization with plains bison that were introduced into its range in 1925–28 made it difficult to find specimens genetically close to the original wood bison. In 1957, a herd of animals that exhibited valid wood bison characteristics was found. From fewer than 40 animals used for breeding purposes, numbers increased to 450 by 1978, and to over 2 300 by 1987 (Wood Bison Recovery Team 1987). In 1988, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) downlisted the wood bison from endangered to threatened. The chief limitation to further recovery of a healthy population is the presence of bovine diseases among bison in Wood Buffalo National Park, an area that was an important part of the former range. About 85% of the total wood bison population is prospering in good habitat in the Mackenzie Bison Sanctuary, Northwest Territories. There is also a smaller herd at Elk Island National Park, Alberta.

The black bear occurs throughout the Boreal Life Zone and beyond, still occupying most of its historic range. It is a relatively adaptable animal, and most of its populations appear to be stable or increasing. Regional population estimates are as follows: Northwest Territories, 5 000; Yukon, 10 000; British Columbia, 63 000–112 000; Alberta, 43 000; Saskatchewan, unknown but low; Manitoba, 25 000; Ontario, 65 000–75 000; Quebec, 60 000; Newfoundland/Labrador, 6 000; Nova Scotia, 3 300; New Brunswick, unknown; and Prince Edward Island, extirpated. A black bear survey conducted by the Canadian Parks Service revealed surprisingly small populations in mountain parks (V. Geist, University of Calgary, personal communication). A growing demand for bear gall bladders has given rise to a lucrative international traffic, legal and illegal, that poses an ongoing threat to all bears. Trends for some other species found in the Boreal Life Zone are shown in Table 6.5.

Prairie Life Zone

The Prairie Life Zone has probably undergone more alteration from its original natural condition than any other life zone in Canada. More than 80% of the native prairie landscape and about 75% of the aspen parkland (a mixture of wooded areas, water, and grasslands) have been transformed by agriculture and, to a lesser degree, urbanization and industrialization (Prairie Conservation Action Plan 1989; see also Chapters 17 and 26). Such transformations have drastically altered wildlife communities. Populations of Piping Plover, Burrowing Owl, Ferruginous Hawk, Loggerhead Shrike, and Baird's Sparrow are considered endangered or threatened. The swift fox and black-footed ferret have been extirpated.

As part of an attempt at reintroduction, captive-bred swift foxes were released in 1983 near Manyberries in southeastern Alberta. Although the long-term feasibility of the reintroduction is still being assessed, more than 400 foxes have been released in Alberta and Saskatchewan, and at least 13 pairs successfully raised young in 1990 (S. Brechtel, Alberta Forestry, Lands and Wildlife, personal communication). A significant success story is that of the White Pelican (see Box 6.2), a bird species that nests in colonies on lakes principally in the Prairie Life Zone.

Agriculture and urbanization have reduced the number of potholes, sloughs, and other wetlands in the prairies; about 70% of the wetland habitat in the Prairie Life Zone has been lost (Environment Canada 1986), and 78% of wetland margins have been modified by agricultural practices (Didiuk and Caswell 1988). As a result, the number of ducks breeding on the prairies has plummeted. Figure 6.5 shows trends in the number of breeding ducks in western Canada and in the number of ponds that offer suitable breeding habitat. Figure 6.6 shows that, on average, Northern Pintail populations have declined 54% since 1955, whereas those of Mallard have declined 86% (Environment Canada 1990). Populations of snipe, coot, and other

BOX 6.2

The White Pelican: a species regained

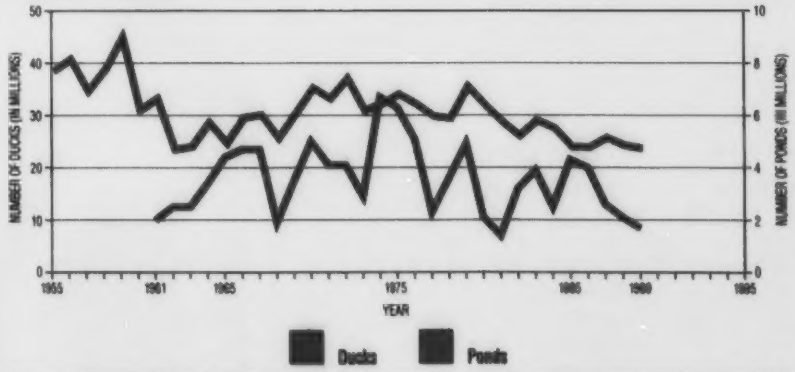
To date, only one species designated as threatened in Canada has recovered sufficiently to be removed from the COSEWIC list. The White Pelican, once common on inland lakes from northwestern Ontario to British Columbia, began to decline across much of its range early in the 1900s. The principal threat to the White Pelican was unrestricted hunting. The soaring white water birds, their wings spanning 2.4–3.0 m, made irresistible targets for gunners who, to their shame, seldom, if ever, ate the flesh of the birds, but simply left the carcasses to rot (Taverner 1940). A further danger stemmed from the fact that nesting pelicans are easily disturbed by the arrival of intruders at their breeding colonies on low-lying islands. Poachers, anglers, boaters, and picnickers, whether unwittingly or with malicious intent, could easily disrupt a colony to such an extent that large numbers of abandoned eggs and chicks would die.

By the mid-1970s, it was evident that the White Pelican was facing serious problems. The Canadian population had fallen to about 16 000 pairs, a number which may seem large, but which is actually very small for this colonial nester. Threatened status was assigned by COSEWIC in 1978, and the governments of Alberta, Saskatchewan, and Manitoba undertook protective measures, including the creation of island sanctuaries and the distribution of conservation messages to the public. The Canada Life Assurance Company, whose corporate logo has featured a pelican since 1847, joined in the struggle to save the birds by sponsoring the World Wildlife Fund's White Pelican Program.

Happily, the protective measures paid off. By 1987, a mere nine years after the initial designation, COSEWIC felt that the White Pelican's future was secure enough to remove it from the list. The number of adult birds had increased more than three times over, to 50 000 breeding pairs occupying nearly 70 colonies across western Canada. The case of the White Pelican was a fortunate one, in that the crisis for the species came at a time when the public was ready to give a sympathetic hearing to its plight, and when environmental conditions, as defined in terms of abundant, uncontaminated food and available nesting habitat, were favourable. The task of species recovery is seldom so straightforward. Nonetheless, the removal of the White Pelican from the COSEWIC list represents an important victory.

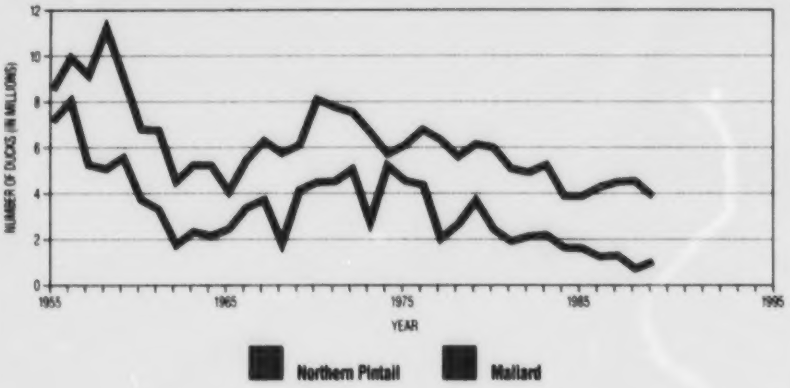
FIGURE 6.5

Trends in the numbers of breeding ducks (all species) and ponds in western Canada



Source: Environment Canada (1990).

Trends in the sizes of breeding populations of Mallard and Northern Pintail in western Canada



Source: Environment Canada (1990).

aquatic birds have also declined with the disappearance of wetlands. Population trends of some other prairie species are shown in Table 6.5.

Great Lakes/St. Lawrence Life Zone

The Great Lakes/St. Lawrence Life Zone became Canada's industrial heartland by virtue of its rich agricultural potential and superior transportation links with important markets. However, its prosperity has been bought at great environmental cost (see Chapters 18 and 19).

Almost half the endangered and threatened wildlife species in Canada inhabit this life zone, a fact that is hardly surprising in view of the biological diversity of the region and its long history of intensive human activity. The far-reaching changes imposed on natural ecosystems in the Great Lakes/St. Lawrence Life Zone by agriculture, manufacturing, urbanization, and transportation have rendered a total of 46 species endangered or threatened. They include 2 mammals, 5 birds, 8 fish, 4 reptiles, 1 amphibian, and 26 plants (see Table 6.3). Unrestricted commercial fishing accomplished the extinction of the blue walleye, the deepwater cisco, and the longjaw cisco, as well as the near eradication of three other species of cisco. The copper redhorse is the only threatened species that is endemic to this life zone.

Many of the endangered and threatened species of this life zone are intimately associated with the extension into southwestern Ontario of the Carolinian deciduous forest ecosystem, a floral and faunal complex that is more typical of the southeastern and central United States (Hackman 1989). The Kentucky coffee tree, cucumber tree, and eastern prickly pear cactus are among more than a dozen endangered or threatened plant species that reach the northernmost limit of their range in extreme southwestern Ontario. Two snakes, the blue racer and the Lake Erie water snake, and one amphibian, Blanchard's cricket frog, are endangered vertebrates that are specific to the Carolinian ecosystem. Also found in this region are representatives of subtropical groups of beetles that live nowhere else in Canada (Danks 1988).

Coastal dunes around the Great Lakes are a habitat type that has suffered serious deterioration from human activity. Cottage development and intense recreational use have damaged dune-stabilizing vegetation, and many plants living in the wet areas behind the dunes, including various species of native orchids, have been wiped out or severely reduced in numbers. The Piping Plover once nested in this habitat but does so no longer.

The aquatic environments of the Great Lakes and the St. Lawrence River have been badly degraded by industrial development, watershed manipulation for transportation purposes, and a bewildering array of pollutants (see also Chapters 18 and 19). Human activities have also led to the introduction into the Great Lakes of sea lamprey, rainbow smelt, alewife, and other nonnative fish species (Regier 1987) and to increases in populations of Ring-billed Gull and other scavenging birds that feed on garbage.

Nonnative species now comprise a significant proportion of the biological diversity of this life zone. Many of these, such as the European Starling, have succeeded at the expense of indigenous wildlife. Some, like the zebra mussel (see Box 18.2) and the purple loosestrife (see Chapter 26), can cause serious ecological and economic problems. Population trends for some native species of this zone are found in Table 6.5.

Atlantic Maritime Life Zone

The Atlantic Maritime Life Zone has a long history of intensive human activity. Coastal areas have for centuries been sites for agriculture and fishing, and the rugged upland areas of interior Nova Scotia and New Brunswick have been heavily logged and mined. Forests still cover about 80% of Nova Scotia's land surface and vast areas of New Brunswick, but virtually all of this consists of young second-, third-, and even fourth-growth descendants of earlier forests (Taschereau 1989), and relict stands of old-growth forest are small, rare, and widely scattered. About half of Prince Edward Island is devoted to cropland, and most of the remainder consists of cutover woodlots and spruce regeneration in abandoned farmland.

Throughout the region, loss of appropriate habitat to development has been a significant factor in the extirpation or reduction of large wildlife species, such as the woodland caribou and the eastern cougar.

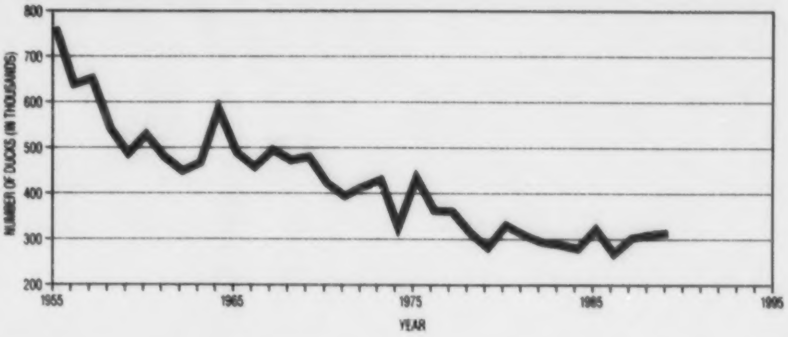
Populations of Herring Gull, Great Black-backed Gull, and other large gulls have been rising in Atlantic Canada during most of the 1900s because of protection from hunting and increased availability of fish waste and garbage. For example, 40% of the commercial fish harvest in Atlantic Canada is discarded, providing a significant food supply for gulls (R.G.B. Brown, Environment Canada, Canadian Wildlife Service, personal communication). Tern populations have declined markedly in the Atlantic provinces over the past few decades, principally as a consequence of competition and predation from expanding gull colonies.

The eastern population of the Harlequin Duck has fallen to fewer than 1 000 birds and in 1990 was declared endangered. The Peregrine Falcon, extirpated from the Maritimes in the 1950s, has been successfully reintroduced in New Brunswick and Nova Scotia. In 1990, five breeding pairs were reported in the region (G. Holroyd, Environment Canada, Canadian Wildlife Service, personal communication).

Coastal estuaries in much of Atlantic Canada provide important breeding and wintering habitat for the American Black Duck. Although this species is declining (Fig. 6.7) across most of its range in North America, aerial surveys of breeding pairs every spring since 1984 indicate a healthy, stable American Black Duck population in the Maritimes (G. Parker, Environment Canada, Canadian Wildlife Service, personal communication). Factors such as pollution, commercial and recreational activity, and fishing do take a toll on waterfowl in this life zone, however, accounting for as much as 15% of duckling mortality along sections of the Nova Scotia coast (Seymour 1990). Population trends for some native species of this zone are found in Table 6.5.

[illegible]

Trend in the numbers of American Black Ducks in wintering areas in North America



Source: Environment Canada (1990).

Marine Coastal Life Zone

All of Canada's marine ecosystems are being degraded by spills of oil and other pollutants. The cost is measured in significant damage to marine life. The 1988 *Nestucca* spill of 875 000 L of oil just off the coast of Washington, for example, is estimated to have killed 20 000 – 30 000 seabirds in the United States and Canada, and marine organisms became so contaminated that areas for shellfish harvesting were closed along much of 150 km of British Columbia's coastline. Smaller, less publicized spills are much more frequent and in total probably kill more wildlife. Even the Arctic Ocean is not immune to this threat. There were 175 known accidental spills in its waters between 1972 and 1985 (Sackmann 1989). Oil and other contaminants also can be transported into the Arctic Ocean from great distances via currents (see Chapter 15).

Improper disposal of municipal and industrial wastes leads to contamination of marine organisms. About 10 400 ha of intertidal area in British Columbia were closed to shellfish harvesting in 1988 because of dumping of untreated sewage by coastal cities (Kay 1989). The state of some wildlife species living in this zone is summarized in Table 6.3.

CONSERVATION INITIATIVES

In September 1990, federal, provincial, and territorial wildlife ministers adopted Canada's first national wildlife policy (Wildlife Ministers' Council of Canada 1990). The policy establishes a framework for the conservation of all of Canada's wild organisms — its biological diversity. The policy addresses several issues that have been touched on in this chapter:

- conserving wildlife habitats and populations;
- broadening the definition of wildlife to include plants and invertebrates;
- providing for wildlife in the development of economic and environmental policies;
- increasing the sustainable benefits from wildlife; and
- controlling introduced and genetically engineered species.

Among other things, the policy recognizes the need to involve aboriginal peoples in wildlife management and research. Ministerial adoption implies a commitment to implementation, which will be assessed by an independent auditor in 1995.

Management of hunting and fishing and establishment of parks and ecological reserves to protect vulnerable habitats (see Chapters 7 and 26) have been primary vehicles for protecting and restoring wildlife populations. Conservation of habitat reflects a growing awareness that environmental protection depends on the preservation and enhancement not only of individual species, but of whole ecosystems. Several provinces are cooperating with landowners and nongovernment organizations, such as the Nature Conservancy of Canada, Wildlife Habitat Canada, and World Wildlife Fund Canada, to increase the number and size of protected areas with significant natural biological diversity (see Chapter 26).

Besides establishing protected areas, Canada has a long history of protecting dwindling populations of large, rare wildlife species. The public efforts on behalf of Whooping Crane, plains bison, wood bison, and pronghorn antelope are well known. More recent initiatives have broadened the focus to include lesser-known species, such as the swift fox and Piping Plover, and even a few invertebrates, such as the Karner blue butterfly in Ontario, protected under the *Ontario Endangered Species Act*. Governments and nongovernment organizations have also increased their efforts to safeguard endangered vascular plants. A good example is Furbish's lousewort, a small wildflower that came under protection in 1990 through purchase of critical habitat in New Brunswick's upper Saint John River valley.

Success stories in the annals of species protection and recovery have included the removal of the once-threatened White Pelican from the list of species at risk ("status designations" of the Committee on the Status of Endangered Wildlife in Canada) and the downlisting of the wood bison from endangered to threatened status. The Peregrine Falcon is also showing encouraging recoveries of population numbers.

TABLE 6.6

Percentage of the total number of species, subspecies, or populations in various groupings designated as of 1991 by COSEWIC as endangered, threatened, or vulnerable

Species group	Total number of species [a]	Number of species, subspecies, or populations designated by COSEWIC				
		Endangered[b]	Threatened[b]	Vulnerable[b]	Total[c]	% of "total number of species"
Mammals	193	11	8	19	38	19.7
Birds	578	9	8	17	34	5.9
Fish[d]	1 091	3	10	34	47	4.3
Amphibians and reptiles	83	4	2	6	12	14.5
Plants[e]	4 328	19	22	21	62	1.4
Total	**6 273**	**46**	**50**	**97**	**193**	**3.1**

[a] From "Known species" column of Table 6.1.

[b] Defined in Glossary.

[c] Does not include the 10 extirpated and 9 extinct species.

[d] Includes sharks, bony fish, and lampreys.

[e] Includes only vascular plants, ferns, and fern allies.

Partnerships, or integrated programs and initiatives involving government agencies, nongovernment organizations, and individuals, are becoming increasingly important vehicles for protecting wildlife and habitat — and, hence, the country's native biological diversity. A few examples are discussed below; others are provided in Chapter 26.

Committee on the Status of Endangered Wildlife in Canada (COSEWIC)

Although the wood bison, Whooping Crane, and a few other species have been receiving special protection for the past 50 years or more, it was only in the 1970s that a national initiative was undertaken to identify all the wildlife species that are at risk in Canada. In 1976, federal, provincial, and territorial wildlife agencies and three nongovernment organizations established a committee to assess and designate the levels of susceptibility of Canada's rare animals and plants. This was an important first step towards establishing objective conservation and preservation priorities in Canada.

As of 1991, COSEWIC has reviewed reports on, and assigned status to, 212 species, subspecies, or populations of native wild animals and plants; 64 others have been considered and found to require no designation at this time. Table 6.6 shows that 193 species are currently listed as endangered, threatened, or vulnerable. Another 10 are considered extirpated, and 9 are extinct.

These numbers represent only that handful of species whose status has been reviewed so far; the actual number at risk is undoubtedly considerably higher in some groups. For example, as many as 38 of 83 species (46%) of reptiles and amphibians in Canada may be found to be at risk when their status is eventually examined (F. Cook, Canadian Museum of Nature, personal communication). Over 100 additional plant species are likely to be designated as endangered or threatened once the necessary evaluations have been completed. Of the 3 269 native species of vascular plants in Canada, nearly one-third eventually may be recognized as rare to some degree, although not necessarily requiring conservation action at this time (Argus and Pryer 1990).

Recovery of Nationally Endangered Wildlife (RENEW)

No federal or provincial laws in Canada require governments to institute recovery action for species that COSEWIC has designated as being at risk. However, in 1988, to address the growing imbalance between designation and recovery, government agencies established an organization and a strategy called Recovery of Nationally Endangered Wildlife (RENEW). According to RENEW policy, a recovery plan for each new species, subspecies, or population of mammal, bird, fish, reptile, and amphibian designated as endangered, threatened, or extirpated will be devised within two years of the date of its designation by COSEWIC. It is expected that invertebrates and plants will eventually be added to the plan. Either under the auspices of RENEW or independently, recovery plans have been started or completed thus far for 11 mammals, 15 birds, and 1 fish (Table 6.7).

Endangered Species Recovery Fund

Environment Canada, World Wildlife Fund Canada, the Canadian National Sportsmen's Shows, and the Natural Sciences and Engineering Research Council of Canada have cooperated in the Endangered Species Recovery Fund. Initiated in 1988, the fund sponsors projects that improve the status of endangered wildlife and habitat or arrest degradation of either. By 1990, funds of over $1 million had been allocated for 48 approved projects — 24 on birds, 13 on mammals, 3 on reptiles and amphibians, 1 on fish, and 7 on plants.

North American Waterfowl Management Plan

The North American Waterfowl Management Plan was devised by Canada, the United States, and Mexico as a combined response to public concern over the loss of North American wetlands and the consequent reduction in populations of waterfowl and other species that depend on wetland habitat.

Protection and recovery efforts for endangered and threatened mammals, birds, fish, and amphibians and reptiles

Group and species	Killing/ disturbance regulated by law	Key habitat protected	Species bred in captivity	Reintroduced; new populations	Recovery plan	
					Started	Finished
Mammals						
Beluga						
• eastern Hudson Bay pop.	x	—	x	—	—	—
• southeastern Baffin Island pop.	x	—	x	—	—	—
• St. Lawrence River pop.	x	x	x	—	x	—
• Ungava Bay pop.	x	—	x	—	—	—
Bowhead whale	—	—	—	—	—	—
Eastern cougar	x	—	x	—	—	—
Harbour porpoise						
• western Atlantic pop.	x	—	x	—	x	—
Humpback whale						
• North Pacific pop.	x	—	—	—	—	—
Newfoundland pine marten	x	—	—	—	x	—
Peary caribou						
• Banks Island pop.	x	—	x	—	x	—
• high-arctic pop.	x	—	x	—	x	—
• low-arctic pop.	x	—	x	—	x	—
Prairie long-tailed weasel	x	—	—	—	—	—
Right whale	x	—	—	—	—	x[a]
Sea otter	x	x	x	x	x	—
Vancouver Island marmot	x	x	x	x	x	—
Wolverine						
• eastern pop.	x	—	x	—	—	—
Wood bison	x	x	x	x	x	—
Woodland caribou						
• Maritime pop.	x	x	—	—	x	—
Birds						
Baird's Sparrow	x	—	—	—	x	—
Burrowing Owl	x	x	x	x	x	—
Eskimo Curlew	x	—	—	—	x	—
Ferruginous Hawk	x	—	—	—	x	—
Harlequin Duck						
• eastern pop.	x	—	x	—	x	—
Henslow's Sparrow	x	—	—	—	x	—
Kirtland's Warbler	x	—	—	—	x	—
Loggerhead Shrike						
• eastern pop.	x	—	—	—	x	—
• prairie pop.	x	—	—	—	x	—
Marbled Murrelet	x	—	—	—	x	—
Mountain Plover	x	—	—	—	—	—
Peregrine Falcon						
• subspecies *anatum*	x	—	x	x	—	x
• subspecies *tundrius*	x	x	x	—	—	—
Piping Plover	x	—	—	—	—	x
Roseate Tern	x	—	—	—	x	—
Spotted Owl	x	—	—	—	x	—
Whooping Crane	x	x	x	x	—	x

TABLE 6.7 (CONT'D)

Group and species	Killing/ disturbance regulated by law	Key habitat protected	Species bred in captivity	Reintroduced; new populations	Recovery plan	
					Started	Finished
Fish						
Acadian whitefish	x	—	—	—	—	—
Aurora trout	x	x	x	x	—	x
Black redhorse	x	x	—	—	—	—
Blackfin cisco	x	—	—	—	—	—
Copper redhorse	—	—	—	—	—	—
Enos Lake stickleback	—	—	—	—	—	—
Great Lakes deepwater sculpin	x	—	—	—	—	—
Lake Simcoe whitefish	x	x	—	x	—	—
Margined madtom	x	—	—	—	—	—
Salish sucker	—	—	—	—	—	—
Shorthead sculpin	x	—	—	—	—	—
Shortjaw cisco	x	—	—	—	—	—
Shortnose cisco	x	—	—	—	—	—
Amphibians and reptiles						
Blanchard's cricket frog	x	x	—	—	—	—
Blue racer (snake)	x	x	x	—	—	—
Eastern massasauga (rattlesnake)	x	x	x	—	—	—
Eastern spiny softshell (turtle)	x	—	—	—	—	—
Lake Erie water snake	x	—	x	—	—	—
Leatherback (turtle)	x	—	—	—	—	—

[a] Plan available for adjoining U.S. population only.

Source: Updated from Dauphiné (1989).

BOX 6.3

What can I do?

No amount of scientific expertise can hope to sustain and protect wildlife populations in Canada unless there is a strong and assertive public interest. In Canada today, at least 19 national, 84 provincial, and 205 local conservation and anglers' and hunters' organizations are lobbying governments on behalf of wildlife and conducting their own hands-on research and protection projects.

Individuals who are wondering how to get involved in this task on a personal level might consider the following proven starting points:

- Join an environmental, conservation, or natural history organization in your community.
- Become informed. Read widely about the value of wildlife and the challenges facing our native flora and fauna.
- Volunteer time, energy, and money to assist local conservation efforts, such as cleanups of natural areas and enhancement or protection of wildlife habitat.
- If you own land, set some of it aside for wildlife, and take steps to make it attractive to native species.
- Encourage your employer to consider the benefits of business policies and programs that support sound environmental values.
- Know and abide by the laws established to protect wildlife, and encourage your friends to do the same.

(For a more detailed discussion of the plan, see Chapter 26.) The plan's principal objective is to restore waterfowl populations to the levels of the 1970s by the year 2000 through enhancement, restoration, and development of waterfowl habitat. A major goal is to achieve and maintain a breeding population of 62 million ducks, enough to produce a fall flight of 100 million. The 1988 breeding population level for ducks was about 52.5 million, with an estimated fall flight of only 66 million. This goal is being pursued through cooperative joint ventures among federal, state, and provincial/territorial governments, nongovernment organizations (e.g., Wildlife Habitat Canada and Ducks Unlimited Canada), and private industry. For example, the Saskatchewan Implementation Strategy, part of the Prairie Habitat Joint Venture, is a 15-year, $438 million program affecting 2.3 million hectares of land, with the goal of producing 3 million breeding Mallards by the year 2000.

The North American Waterfowl Management Plan transcends a narrowly defined concern for waterfowl and other wetland wildlife and encourages implementation of resource management practices that will increase overall environmental quality, including water and soil quality, genetic diversity, drought-buffering capacity, and pollution management. The plan complements the Permanent Cover Program of the National Soil Conservation Program and operates in cooperation with Prairie Care (Conservation of Agriculture Resources and the Environment) and the Crop Insurance Program (Waterfowl Damage Compensation and Prevention).

Wildlife management boards

Native people have a special interest in wildlife, largely because wildlife continues to be important to the sustenance of their traditional way of life. Comprehensive aboriginal land claims, covering most of Yukon and the Northwest Territories, are either in legislation or under negotiation (see Chapter 15). With the signing of these arrangements, aboriginal people will have a direct say in wildlife management in Canada's North. Wildlife management boards, consisting of 50% native and 50% government representation, are being established to make recommendations or decisions related to wildlife management. Boards that have been established to date have shown an encouraging degree of commitment to reaching consensus on their recommendations. Among their accomplishments thus far are reduced hunting quotas for barren-ground grizzly bears and a reduced harvest of beluga in Cumberland Sound, Baffin Island.

CONCLUSION

Canada possesses a great wealth of wildlife. Preserving its biological diversity is an integral part of the larger goal of protecting the health of our environment. However, wildlife is under pressure throughout the country from a wide array of human activities. Agriculture, forestry, and urban, industrial, and resource development continue to effect changes in the quality and quantity of wildlife habitat over large areas. The results are seen in declining populations and extinction of species. Likewise, the far-reaching effects of toxic contaminants and acidic deposition continue to degrade the health of natural communities and ecosystems. Climatic change is expected to affect wildlife in significant and, as yet, largely unknown ways; it represents a potential peril for many species.

Our awareness and understanding of the current status and future trends of Canada's biological diversity depend largely on the systematic collection of accurate data for scientific research and analysis. Although it is possible to roughly sketch conditions and trends affecting Canada's wildlife today, too little is known of most species and communities to justify placing much confidence in the hope that their sustainability for the future is assured. Much more needs to be known before Canadians will be able to anticipate and prevent irreversible declines in species populations and the permanent loss of biological diversity.

Progress is being made in the identification of endangered, threatened, and vulnerable species and in the formulation of plans to protect and rehabilitate them. Although parks and ecological reserves provide protection for some areas of special importance to wildlife, only a small proportion of all species can be preserved through these special measures. The future of Canada's native flora and fauna depends more on the will of Canadians to insist that decisions concerning land use and resource development, whether by the public or by the private sector, must reflect sound ecological values. Effective environmental partnerships between governments, landowners, industries, and nongovernment organizations, all accountable to an informed and active public, are the keys to sustaining healthy wildlife.

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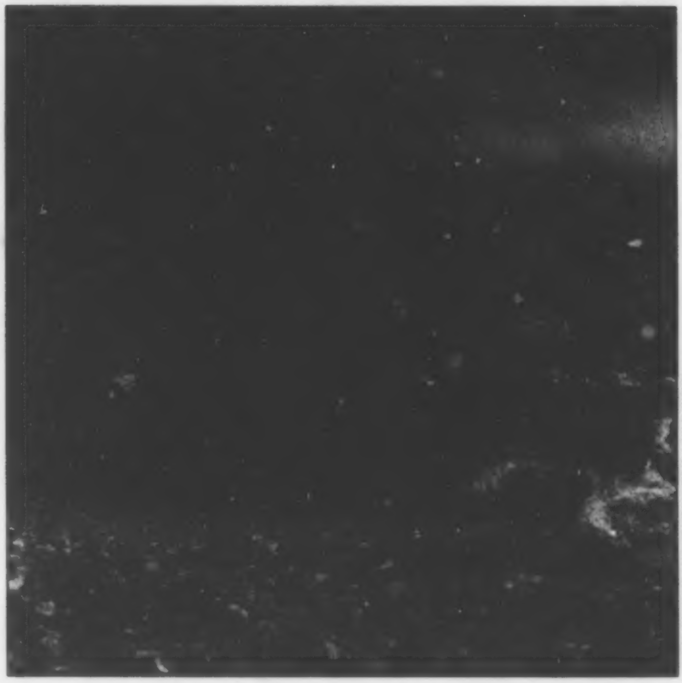

COURTESY OF INDUSTRY, SCIENCE AND TECHNOLOGY CANADA, OTTAWA

HIGHLIGHTS

There are many kinds of protected areas in Canada, from small ecological reserves and historic sites to large national or provincial parks and game sanctuaries. All play an important role in preserving our natural and cultural heritage.

▪

In total, about 7% of the country currently has some degree of protection. Of this amount, about half is strictly protected, i.e., protected from all commercial extractive activities. The federal Green Plan recommends that Canada set aside 12% of its total area as protected space.

▪

Since 1986, the area of national parks in Canada has increased 28% and provincial parks with equivalent protection 14%.

▪

Establishing park boundaries does not guarantee protection of species — protected areas are still subject to the effects of human overuse, acidic precipitation, and air and water pollution from sources outside their boundaries. For example, Kejimkujik National Park has been placed on the World Conservation Union's endangered wilderness list because of the effects of acid rain.

▪

Although protected areas are essential for the preservation of ecological diversity, most protected areas are too small to protect the full range of plant and animal species that they originally contained. Environmental conservation and stewardship programs need to be extended to areas outside the boundaries of parks, reserves, and other protected sites.

▪

In many parts of Canada, the opportunity to establish protected natural ecosystems has already vanished. For example, only scattered remnants of southern Ontario's Carolinian forest are left, the once-vast grasslands have been reduced to isolated relics of native prairie, and the virgin Acadian forests of the Maritimes are almost completely gone.

▪

New approaches to protecting significant areas include acquisition of lands by private organizations and businesses, and government–private citizen legal agreements. For example, many land parcels along the Niagara Escarpment in Ontario are protected by legal agreement rather than acquisition.

▪

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INTRODUCTION

Protected areas are special places, gateways to our natural and human heritage. They celebrate the beauty and the infinite variety of our land and its life, and our adaptation to it over time. They are areas where we can learn about our past, and sanctuaries where nature is allowed to evolve in its own way, as it has done since the dawn of time. These are havens not only for wildlife, but also for the human spirit.

There are many different kinds of protected areas in Canada: national parks, provincial parks, game preserves, bird sanctuaries, outdoor recreation parks, historic parks, and more. They range in size from vast wilderness expanses such as the Thelon Game Sanctuary and Wood Buffalo National Park (both bigger than several European countries) to tiny pockets of wildness as small as a few hectares (e.g., 5-ha Brackman Island, the last undeveloped island in the Gulf Island Archipelago between Vancouver Island and the mainland); from individual buildings and structures (e.g., Prescott House in Nova Scotia or the vessel St. Roch in Vancouver) to large urban districts in Quebec City or protected streetscapes in Niagara-on-the-Lake, Ontario.

Although we often distinguish between areas protected for their natural values and those set aside for cultural reasons, all protected areas form part of a continuum. Urban areas are as much a part of our environment as pristine wilderness. Indeed, few parts of the globe do not bear some witness to man's presence, and most cultural sites have been shaped by the natural environment.

Historic sites often reflect society's past relationships with the environment; they therefore allow us to look back and track how Canadian society has depended upon, used, and even abused the environment over time. For example, our early reliance on the fur trade is illustrated in many historic sites; early Saskatchewan homesteads document the wave of settlement and the development of summerfallow; and sites commemorating the forest industry can provide us with useful information on how present and past generations have used one of our great natural resources.

The purposes of protected areas in Canada are diverse. They range from the preservation of large portions of representative ecosystems or cultural landscapes to single-purpose areas, such as a wetland purchased for the protection of waterfowl, or a historic site commemorating a specific event in Canadian history. Similarly, the level of protection that is afforded can vary. Many ecological reserves enforce strictly controlled access. Other protected areas encourage intensive recreation, allow certain commercial extractive activities, or allow the manipulation of the environment for habitat management or similar reasons. Many protected areas, particularly the large ones, fulfil more than one purpose and are zoned for different levels of protection and a corresponding variety of uses. In the case of cultural heritage, a number of sites are protected in accordance with their heritage value through outright ownership by federal or provincial governments. Others, generally privately owned, may be subject to legislative control, such as federal heritage railway stations and sites covered by provincial and territorial historic resources legislation.

Protected natural areas can contribute to the achievement of global environmental goals. They can allow essential ecological processes to continue to operate, can help maintain biological diversity, or can promote the sustainable use of the natural environment. As such, protected areas are essential components of any nation's environmental strategy. The 1987 report of the World Commission on Environment and Development (more commonly known as the Brundtland Report) described protected areas as an indispensable prerequisite for sustainable development and called on all nations to complete a network of protected areas to conserve representative samples of the Earth's species and ecosystems.

> **“Deterioration or disappearance of any item of the cultural or natural heritage constitutes a harmful impoverishment of the heritage of all nations of the world.”**
>
> — United Nations Educational, Scientific and Cultural Organization (1972)

No similar goal has been established for the protection of the world's human heritage places. Indeed, although citizens feel strongly about human heritage and the need to conserve it, cultural heritage advocates in Canada have been less successful than their natural heritage counterparts in giving effective voice to the cause. But as Northrop Frye pointed out many years ago, "we are also developing some sense of the need for a kind of human ecology, of conserving not only our natural but our cultural and imaginative resources" (Frye 1975).

Although protected areas can contribute significantly to the achievement of sustainable development, alone they cannot achieve the essential goals of maintaining biological diversity or conserving the outstanding symbols of our human heritage. Nevertheless, they are, more than ever, seen as models of environmental and cultural heritage stewardship and an important legacy to be preserved and expanded for future generations.

There is growing concern, however, over the ability of protected areas to achieve their environmental and cultural heritage objectives. Designating a protected area does not automatically secure the preservation, in perpetuity, of the ecological or cultural integrity of the resources within its boundaries. Not only do protected areas suffer from internal pressures such as poaching, vandalism, and recreational overuse, but they are increasingly surrounded by development on adjacent lands and subjected to external stresses for which legal boundaries are no match: acid rain; global warming; water pollution from upstream sources; heavy traffic; and long-range atmospheric transport of toxic chemicals.

Furthermore, not all of the diverse Canadian landscape and seascape — natural and historical — is adequately represented in the country's various protected areas. Canada is composed of a wide variety of ecologically distinct units, each with characteristic species and features. Preserving the full range of this diversity would require that all ecological regions be represented in the country's various systems of protected areas. When it comes to human heritage, the task of deciding what to preserve is still more complex. Our history, which is multidimensional in terms of time, space, and human activities, has left a legacy that would challenge the most confident evaluator of representativeness. In this case, the definition of human history themes, rather than physiographic delineations, can provide the framework for achieving a fuller representation of our human heritage.

An assessment of the state of protected areas requires an examination of two basic questions. First, how effectively do protected areas succeed in preserving our natural and cultural heritage within their boundaries? Second, are there enough protected areas? This chapter describes the major programs of protected areas in Canada and examines how well they are addressing these two key issues.

The focus of this chapter is primarily on natural protected areas. In the cultural context, there is still much work to do in systematically inventorying Canada's protected cultural places, in analyzing the threats to the protection of our cultural heritage, and in defining the measures that will be used to assess the effectiveness of various protective mechanisms and the degree to which the protection of cultural heritage sites serves the long-range goals of sustainable development.

CANADA'S MOSAIC OF PROTECTED AREAS

Historical and philosophical context

The first protected areas in Canada were set aside shortly after Confederation. The rationale for these initial efforts in establishing protected natural areas in Canada was twofold: to preserve outstanding scenic areas for outdoor recreation and tourism; and to protect wildlife habitat in order to ensure continued hunting opportunities. Among the nation's first protected areas were municipal parks, such as Montreal's Mount Royal (1872), and Canada's first national park, at Banff (1885). The Ontario government established the country's first provincial park, Algonquin, in 1893 (Eidsvik 1989).

Some early systems of protected areas grew to immense proportions before gradually being reduced. In the Canadian North, for example, reserves were established as early as 1894 to protect game for native hunters. This system of reserves grew to include, by 1938, 1.35 million square kilometres, or well over one-third of the Northwest Territories! After 1948, the system was gradually reduced in size, and today only a few of the smaller of these reserves still remain (Kovacs 1985).

Protected areas systems have yielded to development in other parts of Canada as well. In Saskatchewan, for example, some 267 km^2 of upland habitat included in federal migratory bird sanctuaries in 1925 were reduced to less than 17 km^2 by 1956 for agricultural purposes.

Despite these earlier trends, recent years have seen a resurgence of interest in protected spaces. Today, over 120 different government and private programs in Canada are involved in acquiring and managing lands for conservation (A.M. Turner, Environment Canada, State of the Environment Reporting, personal communication), and the purpose of protected areas has expanded to incorporate a broad range of objectives (see Table 7.1). Although recreation, tourism, and consumptive use of resources are still common goals, the rationale for protected areas has broadened, partly in recognition of the range of values that can be ascribed to natural areas. Protected areas can, and often do, fulfil more than one purpose. National parks, for example, protect species and ecosystems and provide opportunities for education and enjoyment.

Until a generation ago, protected areas were perceived as fortresses, protected from development or exploitation by

TABLE 7.1

Primary conservation objectives for protected areas

- Maintain essential ecological processes and life-support systems
- Preserve genetic and biological diversity
- Protect aesthetic values and natural ecosystems
- Conserve watersheds and their production
- Control erosion, sedimentation, and soil depletion
- Maintain air quality
- Protect habitat of representative as well as rare and endangered species
- Provide opportunities for ecotourism and recreation
- Provide opportunities for research, education, and monitoring
- Contribute to sustainable use and eco-development
- Protect natural and cultural heritage
- Retain future options

Source: World Conservation Union (1990).

legal boundaries and an independent management regime. Most protected areas were buffered from human impacts by the wild lands surrounding or adjacent to them. Indeed, many parks, particularly the mountain parks, with their town sites and visitor facilities, were actually islands of civilization in a "sea of wilderness."

Today, the situation has changed. Threats originating from within protected areas (e.g., recreational overuse) and without (e.g., acid rain) are intensifying. Many parks and reserves are becoming ecological islands in a sea of development. Their ability to withstand stresses and maintain genetic diversity is being substantially reduced. Species have disappeared or are at risk in many areas, including some of the larger parks and reserves.

Protected areas, therefore, no longer exist in isolation, immune to the effects of activities occurring in the surrounding regions. Agencies responsible for the management of protected areas are realizing that there must be a continuity between what is protected and what is not. The addition of "buffer zones" adjacent to protected areas is one potential way of achieving this, although it has not yet been applied extensively in Canada.

Recent years have seen other changes in the philosophy of protected area management. Programs have expanded their focus. For example, the protection of freshwater and marine areas has grown in importance. The federal government has expanded the national parks system to include national marine parks, and Canada's Green Plan called for the establishment of three new national marine parks by 1996 and an additional three marine parks in areas to be confirmed by the year 2000.

Governments are no longer perceived to be exclusively responsible for protective action. Over the last several decades there has been a remarkable growth in private stewardship programs. An increasing number of private landowners have dedicated land to conservation purposes, thereby expanding the land base managed for the protection of species and habitats.

As protected area programs evolve, a clear goal is emerging for natural heritage preservation — a network of representative and outstanding ecological sites, large and small, public and private, that function in an integrated fashion to maintain ecological diversity and essential ecological processes. Such a network will contribute not only to environmental quality, but to the long-term sustainability of our economy and to a higher quality of life.

Targets for protection

Globally, as well as nationally, the need to safeguard biological diversity and ecological integrity is more urgent than ever.

Of all the world's countries, Canada is exceeded only by Denmark,[1] the United States, and Australia in the actual surface area dedicated to parks and other protected areas (Organization for Economic Co-operation and Development 1989; World Resources Institute 1990). However, many nations surpass Canada in the proportion of their land that is protected. In fact, according to the World Resources Institute (1990), Canada affords strict protection to 3.7% of its land area, compared with an average of 4.0% for all nations of the globe (these statistics refer only to areas of at least 10 km^2 and exclude sites protected by local authorities or private organizations, as well as those where consumptive uses of wildlife are permitted).

Other, more inclusive estimates of the amount of Canada's land and fresh water under protected status range from 6.3 to 7.4%. The variation in these estimates stems mainly from differing criteria for inclusion, as well as differences in data availability; for example, some estimates include privately owned reserves, whereas others do not.

Hummel (1989) indicated in *Endangered spaces* that 6.3% of Canada's landscape was legally protected by federal, provincial, and territorial governments. He added, however, that only 2.6% can be considered protected if one excludes areas where logging, mining, or hunting are permitted. In the 1991 *Endangered spaces progress report*, the World Wildlife Fund Canada reported that 3.4% of Canada lies in protected areas where industrial activities such as logging, mining, and hydroelectric development (but not hunting) are prohibited.

Canada's Green Plan reported that governments and private conservation organizations together have protected about 6.9% of the country (Government of Canada 1990).

The National Conservation Areas Data Base, jointly developed by Environment Canada and the Canadian Council on Ecological Areas, currently identifies about 3 000 sites with an environmental conservation purpose under federal, provincial, or territorial management, covering about 708 000 km^2, or about 7.1% of Canada's land area. An additional 32 000 km^2, approximately, are reported held by nongovernment organizations. Adding this to the previous total would mean that about 740 000 km² (7.4% of Canada) have some degree of protection (Turner *et al.* 1991).

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[1] Figures for Denmark include vast protected space in Greenland.

How much protected land is enough? In 1982, the Third World Congress on National Parks and Protected Areas recommended that each nation dedicate 10% of its territory to protected areas. This target was later endorsed by the United Nations Environment Programme. The World Commission on Environment and Development also endorsed this recommendation in the Brundtland Report and suggested tripling the nearly 4% of the planet that it estimated at the time was managed explicitly for conservation.

In accordance with these recommendations, Canada's Green Plan, released in December 1990, called for the protection of 12% of Canada's total territory within a network of protected areas in order to protect representative samples of the nation's ecosystems (Government of Canada 1990). Despite discrepancies in the estimates of how much land and fresh water are currently protected in Canada, the total falls, as yet, far from that target.

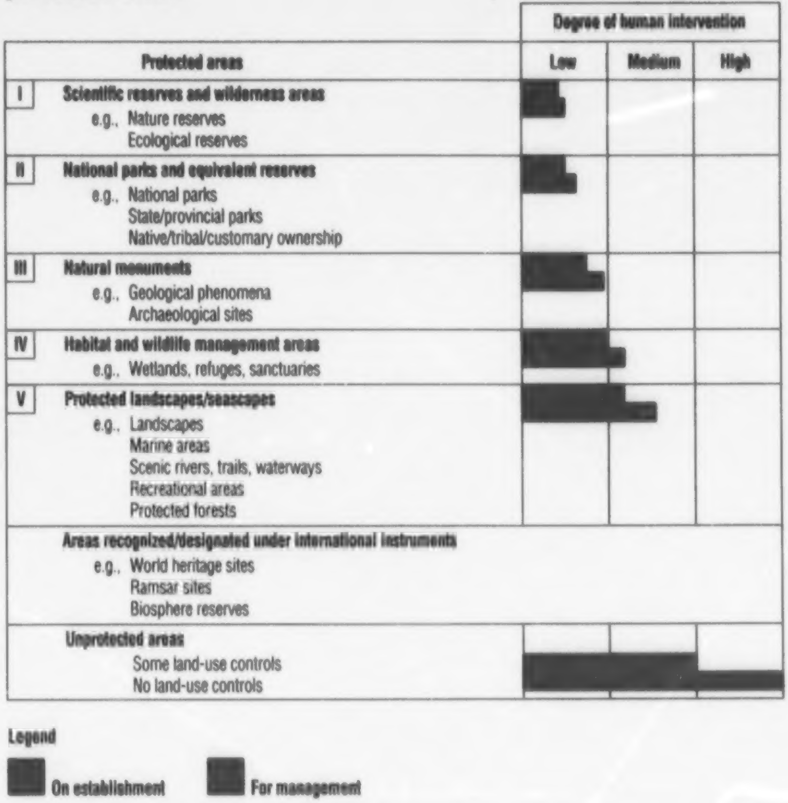
Apart from total area, there are other factors that need to be considered in assessing the mosaic of protected sites in Canada: the degree of protection afforded to each area; its size; its geographic location; and its ecological relevance. Simply designating 12% of Canada's surface area for protection will not, by itself, preserve biological diversity or maintain essential ecological processes.

Degree of protection

An important criterion for distinguishing various kinds of protected areas is the amount of human alteration to the natural environment that is sanctioned within the area. The World Conservation Union (IUCN)[2] and its Commission on National Parks and Protected Areas identify categories of protected areas that are defined largely on the basis of how much human intervention is allowed in each. Figure 7.1 illustrates the updated classification system accepted at the IUCN General Assembly meeting in Australia in November 1990. It identifies five categories of areas that have protection as a primary function. The system aims to discourage the narrow view that protected areas are single-purpose areas. Instead, it promotes a broader concept of varying degrees of conservation and development (Nelson and Eidsvik 1990).

Figure 7.1

IUCN framework for the classification of terrestrial and marine protected areas



Source: World Conservation Union (1990).

No single IUCN category is more important than another. Each offers a different level of protection depending on how much is required to maintain the natural features and the desired values associated with the site. To achieve the full range of objectives listed in Table 7.1, each category is critical. Highly protected pristine areas (i.e., IUCN categories I and II) are essential for the preservation of genetic diversity and maintenance of ecological integrity, as altered ecosystems do not contain the full complements of species and processes that these undisturbed areas contain. Less strictly protected categories, in which varying degrees of consumptive activities (e.g., hunting or logging) are permitted, may protect particular species or habitats. All provide for the maintenance of basic ecological functions, such as protection of watersheds, cycling of oxygen, carbon, and other nutrients, and stabilization of climates. Properly planned and managed, such areas can serve as models for sustainable use of flora and fauna.

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[2] The International Union for the Conservation of Nature and Natural Resources (IUCN) has changed its name to World Conservation Union; however, the acronym has not changed.

Extensive networks of protected areas focus on historical or archaeological resources and artifacts. Where such resources are closely linked to the natural environment, they are included in the IUCN framework and are classified in the category that corresponds with their conservation objectives.

Although Canadian terminology may differ from the IUCN usage in Figure 7.1, the IUCN framework provides a useful international scheme within which to examine protected areas and their contribution to sustainable development objectives.

As the purpose for which Canadian protected areas have been established varies, so does the degree of protection they receive. Ecological reserves, wilderness areas, national parks, and some provincial and territorial parks provide strict protection to natural areas, species, and ecosystems. These fall into IUCN categories I and II.

Other protected areas, such as wildlife management areas and protected landscapes, allow human intervention when it is compatible with their conservation objectives. In such areas (IUCN categories III, IV, and V), controlled commercial extractive activities may be permitted under conditions that do not disrupt the inherent natural values of the site. For example, in some wildlife management areas, hunting is allowed, but activities that alter or destroy wildlife habitat, such as clear-cutting operations, are prohibited.

The extent of legislative protection also differs for different types of protected areas. National parks and some provincial parks have their boundaries defined by legislation. Changes in boundaries or status require legislative approval. Other protected areas are created by order-in-council or private agreement; their protective status or boundaries may be more easily changed.

Protected areas are not closed, self-sustaining systems; they exist within a broader ecological or regional context. If Canadians are to realize the full extent and benefit of their heritage, then management objectives must extend beyond the boundaries of parks, reserves, and historic sites. Good stewardship is our duty to the whole environment, whether we are engaged in preservation, forestry, fishing, agriculture, aquaculture, tourism, recreation, education, or urban development. Only then can current losses of ecological and cultural resources be reversed, in the interest of social and economic goals, as well as environmental objectives.

Size of protected areas

The degree of protection provided within an area will not, of itself, guarantee achievement of sustainable development objectives. Depending on the conservation objectives of a particular site, the size of the area set aside can be just as important. It has been found, for example, that protected natural areas cannot remain intact when completely surrounded by development. Newmark (1987) found, in a study of 14 western North American parks, that 42 species of mammals were eliminated from the parks because of inadequate park size.

How large a reserve should be depends on its purpose. To protect a fossil site, a reserve need be only as big as the site itself. But to provide complete ecosystem protection, there is no upper limit to size. When reserve boundaries are restricted in response to commercial, political, or other considerations, the areas chosen for protection may be very susceptible to transboundary influences and may have little capacity to recover from visitor impacts or natural disasters.

As lands surrounding protected areas undergo more alteration and development, the protected areas themselves become isolated islands of wilderness. Just as oceanic islands around the world have suffered species loss and ecological breakdown after their discovery and exploitation, parks that become "islands" are also vulnerable to the loss of ecological integrity and species diversity. Island biogeographic theory suggests that larger areas support more species and larger, more stable populations. If an ecosystem is reduced in size, the number of species it contains will gradually decline to a new level of equilibrium. As a general rule, a 10-fold reduction in the size of the "island" will cut the number of resident species by half (Webb 1987; Dueck 1990). When a protected area is not completely isolated, however, the application of this theory is complicated by influences from surrounding lands, such as the migration of other species.

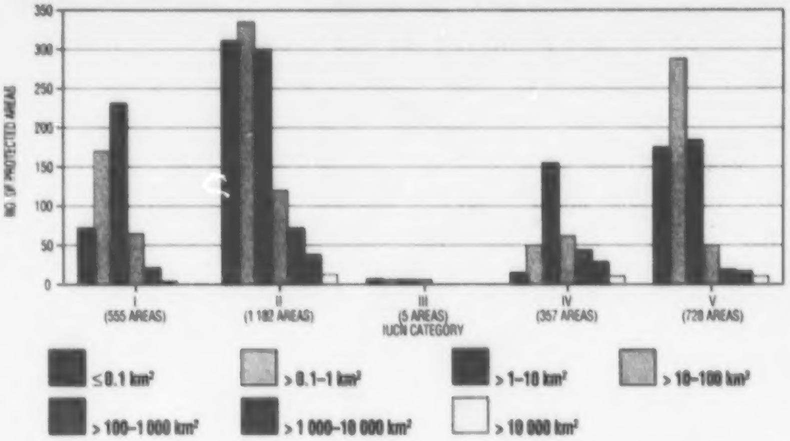
Few protected areas, if any, are large enough to meet the ecological requirements of all the plant and animal communities within them. Reserves in excess of 10 000 km^2, for example, have been recommended to protect populations of a few hundred large carnivores in African savanna (Webb 1987).

Figure 7.2 illustrates the number of Canadian protected areas (excluding private lands and cultural heritage sites) according to size and IUCN category. It shows that 81% (2 285) of protected sites are smaller than 10 km^2; only 0.7% are larger than 10 000 km^2. Approximately 61% (1 737) of protected sites are strictly protected (IUCN categories I and II). Of these, 82% (1 418) are smaller than 10 km^2.

Even the four contiguous Rocky Mountains national parks (Banff, Jasper, Yoho, and Kootenay), one of the largest and most secure protected area complexes in Canada, do not meet the ecological requirements of large carnivores such as wolverines, grizzly bears, wolves, or cougars (Dueck 1990). Sangster (1990) suggested that the minimum viable population of grizzly bears is 393 and that a minimum of 50 000 km^2 of land is needed to support them. The four parks together protect only 20 238 km^2. Although adjacent provincial protected areas add approximately 9 000 km^2 to this total, not even this complex of protected areas is large enough to allow the natural cycles that occur there to totally escape the effects of activities on adjacent unprotected lands.

In general, large reserves have more ecological value than small ones. This is not to say that small reserves have little ecological value. Small reserves can protect critical ecological areas, such as fish spawning beds or staging areas for migratory birds. They may preserve unique cultural features or rare habitats, or they may link larger reserves. They can serve as outdoor education and recreation areas. Furthermore, the geographical relationship of protected areas is important — several small, well-planned reserves can function like a single large one. Nevertheless, in the case of protected natural areas, size is important. How much of an area is to be preserved can be as crucial a consideration as the degree of protection it is given.

Number of protected areas by size and IUCN category



Source: Environment Canada, State of the Environment Reporting, National Conservation Areas Data Base, 1991.

Representation of Canada's ecological regions

Ecological regions are generally defined by overlaying information on such factors as soil, vegetation, landforms, and climate. Representative natural areas can then be identified by locating specific places that exemplify the characteristics of each region. Two existing national frameworks are the Canadian Parks Service natural regions framework and the Canadian Ecological Land Classification framework. Some provinces and territories have developed their own frameworks for the identification of ecological regions.

Natural regions framework

A natural regions concept was first adopted in Canada in 1971 as a framework for the systematic planning of national parks. The Canadian Parks Service divided Canada into 39 terrestrial natural regions and 9 marine regions (later expanded to 29). Each region can be distinguished from others by readily observable differences in biota, physiography, and other environmental conditions (Environment Canada 1971, 1990).

The objective of this framework is to ensure the protection of outstanding representative samples of each natural region. Thus, the number of national parks required and the amount of land to be protected can be more readily defined.

Ecoregions framework

Another national framework to describe the ecological regions of Canada is the ecoregions framework developed by the Canada Committee on Ecological Land Classification. This framework divides the country into 177 ecoregions based on biophysical and geographical characteristics. These ecoregions cover 5 400 more detailed ecodistricts and are themselves included within 40 ecoprovinces and 15 ecozones of less detail (Wiken 1986).

This framework was not designed strictly for planning park establishment, but samples of each of the distinct ecological units it describes would need to be reserved if the full range of Canadian ecological diversity is to be protected.

Provincial frameworks

Since 1970, seven provinces (excluding New Brunswick, Newfoundland, and Prince Edward Island) and Yukon have developed their own natural regions maps. To date, these jurisdictions have defined a total of 274 natural regions (World Wildlife Fund Canada 1991). Some coincide with those of the national ecoregions framework, and some do not. Some definitions vary between neighbouring provinces. Although no single framework is accepted by all conservation agencies in Canada, there is agreement on the strategy of developing "representative" networks of protected areas. In the interest of consistent presentation of data, the national frameworks will be used in this chapter.

CATEGORIES OF PROTECTED AREAS IN CANADA

There are many types of protected areas in Canada — parks, reserves, conservation areas, and sanctuaries, to name a few. Each has a different purpose and its own place in the continuum of Canadian protected areas. Most protected areas, particularly large ones, fulfil more than one purpose. Many contain zones that individually fulfil different objectives within one area. For example, nature reserves in Ontario's Algonquin Provincial Park are zones of strict ecosystem protection within a larger area managed for outdoor recreation and sustainable utilization of forest resources.

For the purposes of this chapter, protected areas in Canada can be grouped into the following categories: ecological reserves, national and provincial parks, managed wildlife areas, protected landscapes, cultural heritage sites, and internationally designated areas.

Ecological reserves

Ecological reserves are protected natural areas where human intervention is kept to a minimum and natural change proceeds unimpeded. Ecological reserves are the areas that are least subject to human influence and correspond to IUCN category I (Fig. 7.1).

Ecological reserves are established primarily to preserve genetic resources and to permit scientific research and appropriate educational programs. They can also serve as yardsticks to measure damage, change, or the rate of recovery of areas disturbed by human activity. Compatible recreational activities, such as hiking or nature observation, are usually allowed but not encouraged (Taschereau 1985). Hunting and commercial resource uses are normally prohibited; however, exceptions occur in some ecological reserves, provided that the activity does not detract from the values for which the reserve was originally established. For example, hunting is permitted at Mistaken Point in Newfoundland, a site primarily noted for its fossils.

In 1991, there were 204 ecological reserves in Canada, ranging in size from less than 1 km² to almost 500 km² and encompassing an area of 2 865 km² (World Wildlife Fund Canada 1991). The proposed Matamek Ecological Reserve in Quebec will be over 700 km² in size and will protect an entire watershed. Table 7.2 shows trends in the number of ecological reserves by jurisdiction for 1985 and 1991.

TABLE 7.2

Ecological reserves, 1985 and 1991

Province/territory	1985	1991	Area (km²)[a]
British Columbia	113	131	1 589
Alberta	0	13	271
Saskatchewan	0	1	8
Manitoba	6	12	570
Ontario	0	0	0
Quebec	12	29	340
New Brunswick	?	5	2
Nova Scotia	0	4	2
Prince Edward Island	0	0	0
Newfoundland	5	8	67
Yukon	0	1	16
Northwest Territories	0	0	0
Total	**136**	**204**	**2 865**

[a] Areas are for 1991, rounded to nearest km².

Note: The following areas are omitted from this table: Pingos Canadian Landmark in the Northwest Territories; and the zones of highest protection in national parks (zone 1) and provincial parks systems in British Columbia and Ontario. These areas are given the same degree of protection as ecological reserves but are not protected under specific ecological reserve legislation.

Source: Boudreau (1988); World Wildlife Fund Canada (1991).

Lands held by nature trusts and other nongovernment agencies involved with nature conservation comprise a small but growing contingent of strictly protected areas (see Table 7.3). Many aim to provide the same degree of protection as ecological reserves.

National and provincial parks

National and provincial parks account for the largest area in Canada where commercial resource extraction and sport hunting are prohibited (IUCN category II) (Fig. 7.1). They protect outstanding natural features, landscapes, and wilderness areas, offer recreation and tourism facilities, and encourage research and education.

Canada's 34 national terrestrial parks cover over 180 000 km² (Table 7.4), or 1.8% of Canada's land and freshwater area. National parks range from 6 km² (St. Lawrence Islands) to 44 807 km² (Wood Buffalo). Three new national parks were established between 1985 and 1990, adding almost 40 000 km² to the system. In addition, two marine

TABLE 7.3

Selected nongovernment conservation lands, 1991

Organization	Area (km²)
Ducks Unlimited Canada	29 000[a]
Nature Conservancy of Canada	340
British Columbia Nature Trust	36[b] (overlap with many parks)
Island Nature Trust, Prince Edward Island	3
Federation of Ontario Naturalists	5
Wildlife Habitat Canada Foundation	over 150
Total	**over 29 534**

[a] Includes protected areas jointly managed among various governments.

[b] 1983.

Source: Turner *et al.* (1991).

TABLE 7.4

National parks, 1990

Natural region	Park name	Province/territory	Area (km²)[a]
Terrestrial parks			
1	Pacific Rim National Park Reserve[b]	BC	500[c]
	South Moresby National Park Reserve	BC	1 470[c]
4	Glacier National Park	BC	1 349
	Mount Revelstoke National Park	BC	260
5	Banff National Park	Alta.	6 641
	Yoho National Park	BC	1 313
	Kootenay National Park	BC	1 406
	Jasper National Park	Alta.	10 878
	Waterton Lakes National Park	Alta.	505
6	Kluane National Park Reserve	Yukon	22 015
8	Nahanni National Park Reserve	NWT	4 766
9	Northern Yukon National Park	Yukon	10 168
11	Wood Buffalo National Park (part)	NWT/Alta.	44 807
12	Wood Buffalo National Park (part)	—	—
	Prince Albert National Park	Sask.	3 875
	Elk Island National Park	Alta.	194
	Riding Mountain National Park	Man.	2 976
13	Grasslands National Park	Sask.	906[c]
18	Pukaskwa National Park	Ont.	1 878[c]
19	St. Lawrence Islands National Park	Ont.	6
	La Mauricie National Park	Que.	544
	Georgian Bay Islands National Park	Ont.	25
26	Auyuittuq National Park Reserve[b]	NWT	21 471
29	Georgian Bay Islands National Park (part)	Ont.	—
	Bruce Peninsula National Park	Ont.	266[c]
	Point Pelee National Park	Ont.	16
	Mingan Archipelago National Park Reserve	Que.	151
30	Forillon National Park[d]	Que.	240
31	Cape Breton Highlands National Park	NS	951
	Fundy National Park	NB	206
32	Kouchibouguac National Park[d]	NB	239
	Prince Edward Island National Park	PEI	26
33	Kejimkujik National Park	NS	384
34	Gros Morne National Park	Nfld.	1 943[c]
35	Terra Nova National Park	Nfld.	399
39	Ellesmere Island National Park Reserve[b]	NWT	37 775
Total			**180 549**
Marine parks			
Georgian Bay	Fathom Five National Marine Park	Ont.	130
West Vancouver Island Shelf	Pacific Rim National Park — marine component	BC	155
West Queen Charlotte Islands	South Moresby/Gwaii Haanas[e]	BC	undefined
St. Lawrence River Estuary	Saguenay Fjord[e]	Que.	undefined
Total			**285**

[a] Rounded to nearest km².

[b] National Park Reserves are proclaimed under the *National Parks Act*, but the final boundaries and regulations are subject to the final resolution of aboriginal land claims.

[c] Lands not yet scheduled under the *National Parks Act*.

[d] These parks have offshore boundaries that include a total of 3 856 km² of marine habitats.

[e] Agreements for parks exist, but they have not yet been established.

Note: Total number of national parks: 34
Total number of marine parks: 2
% of total area of Canada: 1.8%
See Figure 7.4 for location of natural regions.

Source: Environment Canada (1990).

parks have been established, protecting 285 km² of Canada's marine territory. Marine parks share the mandate of terrestrial parks, but commercial fishing and navigation are permitted. Some have cultural heritage value; for example, Fathom Five National Marine Park in Georgian Bay was established for the area's 19 major shipwrecks, as well as to represent the natural history themes characteristic of the Canadian Parks Service's Georgian Bay marine region.

The only national park where a limited amount of commercial extractive use is permitted is Wood Buffalo, where commercial logging persists under agreements originally made before the Canadian Parks Service took over management of the park. The Canadian Parks Service is negotiating to buy the timber rights in order to stop clear-cutting. If these negotiations fail, logging will cease when the current timber licence expires in the year 2002.

Every Canadian province and territory has a parks system. In total, these provide some type of protection for over 148 000 km². Table 7.5 describes the types, number, and extent of provincial parks, wildlife management areas, and wilderness areas. Although traditionally established to provide facilities for outdoor recreation, most provincial parks systems now include parks where the conservation of nature and maintenance of wilderness are primary objectives. Some parks prohibit hunting or commercial extractive activities (IUCN category II); others are managed as multiple-use areas (IUCN categories IV and V). Table 7.6 shows the commercial resource extraction practices in the parks systems of Canada.

Provincial park lands that exclude commercial resource activities increased by 23 306 km², or 14%, since 1985. Major wilderness parks were established in Newfoundland, Saskatchewan, and Manitoba, while Ontario's provincial parks system increased by 155 new parks and grew in area by 40% since 1983.

TABLE 7.8

Provincial and territorial parks, wildlife management areas, and wilderness areas, 1991

Province/territory	Parks		Wildlife management areas		Wilderness areas	
	Number	Area[a] (km²)	Number	Area[a] (km²)	Number	Area[a] (km²)
British Columbia	387	52 506	10	247	1	1 315
Alberta	193[b]	1 417	8	680	8	5 607
Saskatchewan	227	11 560	1 662	15 372	—	—
Manitoba	60	14 318	72	31 833	1	4 065
Ontario	261	63 619	45	9 240	37	618
Quebec	16	4 194	16	67 000	—	—
New Brunswick	48	235	19	3 219	—	—
Nova Scotia	117	111	26	1 417	—	—
Prince Edward Island	42	35	8	33	—	—
Newfoundland/Labrador	75	246	1	618	2	3 965
Yukon	1	114	2	5 918	—	—
Northwest Territories	44	130	3	26 464	—	—
Total	**1 471**	**148 485**	**1 872**	**162 041**	**49**	**15 570**

[a] Rounded to the nearest km².

[b] Includes 132 recreation areas.

Source: World Wildlife Fund Canada (1991)

Managed wildlife areas

This category includes wildlife management and multiple-use areas and generally corresponds to IUCN category IV. Sport hunting and commercial resource utilization on a sustainable basis are usually significant uses of such areas. Managed wildlife areas located in all provinces and both territories encompass over 160 000 km² of land. Most are on Crown land and are dedicated to providing or enhancing habitat for waterfowl, upland game birds, or game mammals. Management strategies vary widely, from strict ecosystem protection (IUCN category I or II) to extensive habitat manipulation to enhance production of a desired species (IUCN category IV). Hunting is often permitted but controlled. Commercial or recreational activities may be permitted, on a case-by-case basis.

The Canadian Wildlife Service administers two systems of federally managed wildlife areas: migratory bird sanctuaries and national wildlife areas. These two types of wildlife areas protect almost as much land as national parks and are a very important component of Canada's protected areas network (Table 7.7).

In 1990, there were 98 federal migratory bird sanctuaries covering an area of 112 622 km² (Fig. 7.3). Two new sites have recently been added to the system, bringing the total number of migratory bird sanctuaries, as of July 1991, to an even 100. Queen Maud Gulf Migratory Bird Sanctuary, in the Northwest Territories, is the largest protected area in Canada — over 62 000 km². Regulations prohibit hunting of migratory birds or the taking of their eggs or nests. The federal government does not always own migratory bird sanctuaries; they can be designated by order-in-council on private lands with the consent of the landowner. Such areas can be deregulated should the landowner revoke consent or the area lose its value to migratory birds.

National wildlife areas are relatively new protected areas, designated by order-in-council under the *Canada Wildlife Act* (1973). Grazing, farming, and other uses may be allowed on a case-by-case basis. Most of the 45 national wildlife areas are small and protect waterfowl habitat in southern Canada (Table 7.7, Fig. 7.3). In all, they protect 3 054 km², although they may overlap with migratory bird sanctuaries.

Two significant national wildlife areas are Polar Bear Pass on Bathurst Island and Vaseux Bighorn in British Columbia. Polar Bear Pass (2 620 km²) is strictly protected from extractive resource activities under the *Canada Wildlife Act*. It is twinned with an ecological reserve in Ireland because of the Brant that migrate between these two areas.

The Thelon Game Sanctuary in the Northwest Territories is one of the largest (55 000 km²) protected areas in Canada. Established in 1927 to protect primarily muskoxen, it is administered by the territorial and federal governments. A federal order-in-council in 1972 prohibited all commercial activities, as well as hunting and trapping, and habitat alteration is forbidden. After extensive public review, the federal government's Conservation Advisory Committee on the Northern Mineral Policy concluded, in 1990, that the Thelon Game Sanctuary should not be opened to mining.

Protected landscapes

In the settled parts of Canada, human interactions with the natural environment have created some landscapes of great beauty. The protected landscape approach attempts to preserve the mosaic of woodlots and farms, coastal villages and wild headlands, wheat fields, and stream valleys that are a distinctive part of Canada's natural and cultural heritage. Although protected landscapes are not automatically safe from abuse, they often encompass sections of land such as ecological reserves or other areas that do receive strict legal protection. Landscape protection may combine government-owned and privately owned protected areas, land-use

TABLE 7.6

Comparison of resource extraction and land-use policies in Canada's parks systems, 1989

	Jurisdiction												
Activity	1	2	3	4	5	6	7	8	9	10	11	12	13
Forestry practices													
Commercial harvest	P	M	M	M	A	P	P	A	M	—	P	—	—
Firewood, etc.	P	P	P	A	A	P	P	P	A	P	P	—	—
Fisheries management													
Sport	A	A	A	A	A	A	A	A	A	A	A	A	A
Commercial	P	P	P	A	A	*	P	P	P	—	P	—	—
Bait fish harvest	P	P	P	—	A	A	P	—	P	—	P	—	—
Fish farming	P	P	P	P	P	—	P	P	P	—	P	—	—
Mining													
Sand and gravel	P	A	M	A	A	P	P	M	A	A	P	—	—
Other	P	A	P	A	A	P	P	P	P	P	P	—	—
Trapping	P	*	*	A	A	*	P	P	P	P	P	A	—
Hunting	P	A	M	A	A	A	P	P	A	P	P	A	A
Wild rice harvest	P	—	A	*	A	*	P	—	—	—	—	—	—
Cottaging	A	*	A	A	A	*	P	—	P	—	P	—	—
Commercial development													
General services	A	A	A	A	A	A	A	A	A	A	A	—	—
Lodges and outcamps	A	A	P	A	A	A	P	P	P	—	P	—	—
Water control structures	A	—	A	A	A	A	P	A	A	A	A	—	—
Utility/transportation corridors	A	A	A	A	A	A	P	A	A	A	A	—	—
Agriculture													
Crop cultivation	P	P	M	P	M	M	M	A	A	M	P	—	—
Haying/grazing	P	M	M	M	A	M	M	A	A	A	P	—	—
Mechanized travel													
Off-road	A	A	P	A	A	A	P	A	P	P	P	A	A
Motor boats	A	A	A	A	A	A	A	A	A	A	A	—	—

Key:
A allowed generally or in some park classes/zones
M allowed for park management purposes only
* to be phased out
P prohibited
— not applicable

1 Canada	5 Manitoba	8 New Brunswick	11 Newfoundland
2 British Columbia	6 Ontario	9 Nova Scotia	12 Yukon
3 Alberta	7 Quebec	10 Prince Edward Island	13 Northwest Territories
4 Saskatchewan			

Source: Watkins (1989).

TABLE 7.7

Managed federal wildlife areas, 1990

Area	No.	Area (km^2)
Migratory bird sanctuaries	98	112 622
National wildlife areas	45	3 054
Total	**143**	**115 676**[a]

[a] The addition of migratory bird sanctuaries and national wildlife areas does not give an accurate portrayal of the exact area protected, as some of the wildlife areas overlap with bird sanctuaries.

Source: Environment Canada, State of the Environment Reporting, National Conservation Areas Data Base, 1991.

guidelines for development outside the formally protected space, land acquisition programs, landowner contact programs, and a range of fiscal and tax incentives to promote protection of woodlots or heritage buildings.

Designation of protected landscapes has come slowly in Canada; yet, in the face of development pressure, important landscapes will disappear if not protected. The Niagara Escarpment, encompassing 1 900 km^2 and over 100 parks, is Canada's best example of a large-scale protected landscape. With passage of the *Niagara Escarpment Planning Development Act* in 1973, Ontario established a planning process and created a commission to ensure that the area would be protected. The management plan aims for a balance between development, preservation, and recreational use.

Ontario's 680-km Rideau/Trent-Severn Waterway is an example of a protected cultural landscape. The Red River Corridor (Manitoba) and the Mackenzie Trail (British Columbia) are other examples of protected areas that include some of the elements of protected landscapes.

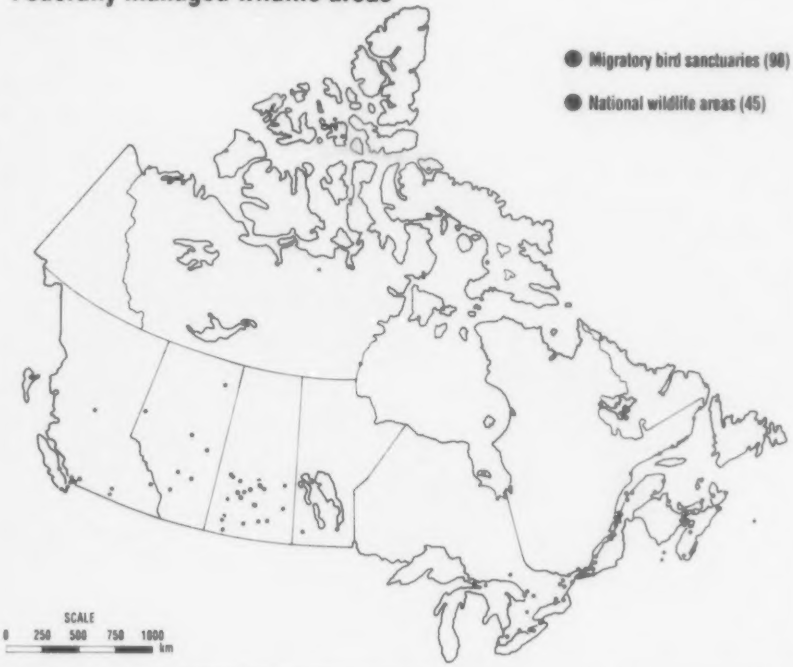
Cultural heritage sites

As protected area programs have evolved, links between Canada's natural and historical origins have attracted more interest. There is no place on Earth that has not felt the impact of human society. Thus, while it is important that we protect natural systems from human impact, it is also essential that we recognize and commemorate the role of society and its evolution. More than 7 800 Canadian cultural heritage sites have been designated or acquired by governments for temporary or long-term protection (Carter 1990). A summary of these sites, by status and by jurisdiction, is provided in Table 7.8.

Understanding the past is central to planning for the protection of cultural heritage sites and may also contribute to the protection of natural ecosystems. Cultural heritage sites often commemorate themes — native history, resource industries, the fur trade — that are intricately linked to the natural environment, and they may, consequently, protect natural resources. They also help us understand the historical roots of current environmental conditions.

FIGURE 7.3

Federally managed wildlife areas


● Migratory bird sanctuaries (98)
● National wildlife areas (45)
SCALE
0 250 500 750 1000
km

Source: Environment Canada, State of the Environment Reporting, National Conservation Areas Data Base, 1991.

Human history in Canada, from the arrival of the first people over 10 000 years ago to the present day, has been marked and shaped by natural forces. Some Canadian heritage rivers, and Canada's first marine park, were designated not only to protect natural heritage but because of their cultural importance. Our history has also been marked by epic struggles to prevail over nature. Cultural heritage sites, therefore, may also celebrate our ability to modify the natural environment. And, of course, many cultural heritage sites simply commemorate events and accomplishments in our history, with minimal reference to the natural environment.

There are some key differences between protection of natural and cultural heritage areas. Whereas we protect natural areas to allow important natural processes to continue, efforts to protect and interpret historic sites may involve alteration of the site to stabilize, maintain, or even rehabilitate it. Although some physical aspects of the site are certainly protected, the degree of intervention may be high.

Acid rain, careless stewardship, and insensitive planning processes may menace natural and cultural sites alike. But cultural sites can also be threatened by nature: erosion can carry away archaeological vestiges; earthquakes and landslides can threaten sites; and the incursions of unchecked vegetation can obliterate them. In such cases, intervention may be necessary to preserve the integrity of a cultural heritage site.

Most of our historic buildings can be preserved only if they have a meaningful contemporary use. Provincial heritage legislation covering provincial and municipal management of the built environment stresses protecting the historic character of a building or district while contemporary life continues in or around it. The intent is to maintain continuity and a sense of place.

At the federal level, sites of national historic significance are designated by the Minister of the Environment under the *Historic Sites and Monuments Act*. This act affords protection only to lands that are under the authority of the Minister. At present, over 100 designated sites fit this category. Hundreds of others fall under the authority of other government agencies or remain in private hands. Those not under federal control must depend on provincial or municipal legislation for protection.

The federal Minister of the Environment is also empowered by the *Heritage Railway Stations Protection Act* to designate properties administered by railway companies under federal jurisdiction and to extend protection to designated stations.

In 1982, the federal government adopted the Federal Heritage Buildings Policy, which aims to ensure that the government itself respects the heritage values of properties of which it is the custodian. All government departments (not Crown corporations) must submit for review all properties over 40 years old. This review is coordinated by the Federal Heritage Buildings Review Office. Buildings deemed to have heritage value may be designated "Classified" or "Recognized." Custodians of "Classified" buildings may not modify, demolish, or dispose of them without reference to the Federal Heritage Buildings Review Office; custodians of "Recognized" buildings must refer potential demolition or disposal to the office.

Because property outside the federal domain is a provincial concern, it is the provinces that can best protect cultural property not under federal government control. All provinces have heritage legislation affording varying degrees of protection to cultural property. In addition, most provinces have historic sites programs for administering their most important properties.

Some recent programs and studies have defined community heritage very broadly — encompassing the natural

and built environments, rural landscapes, and ongoing cultural and economic life. They encourage broad public participation in defining what a community wants to protect, as a guideline for land-use planning and development. Examples of this orientation are the Community Pride initiative of the British Columbia government, the Main Street Revitalization and Heritage Regions programs of the Heritage Canada Foundation, and the Ontario government's Heritage Policy Review Committee.

Although many laws and programs protect cultural properties, they vary from jurisdiction to jurisdiction. There is no common set of standards, and no single, complete inventory of cultural properties. Analysis of the state of protection afforded to such properties is nearly impossible. Analysis is also restricted by a lack of research in this field. The elements required to assess the state of cultural heritage protection in Canada are not in place. Systematic work needs to be done on an inventory and classification of cultural sites; on development of legislation and programs at the federal, provincial, and municipal levels; and on a detailed review of threats stemming from cultural trends, economic factors, and environmental influences. The challenge of the 1990s is for governments, volunteer groups, and the corporate sector to act together to protect and maintain important cultural sites and, where appropriate, stress their links to the natural environment.

There are, however, some foundations on which to build. Late in 1990, under sponsorship of the federal Ministers of Communication and the Environment, a conference of representatives of cultural heritage interests at all levels was held in Edmonton; from this came plans for developing a common Federal Heritage Strategy. There are also some basic tools available. The Canadian Museum of Civilization maintains an inventory of archaeological sites, which is at present used primarily by scholars,

TABLE 7.8

Summary of known protected cultural heritage sites by jurisdiction, 1990

Jurisdiction	Ownership	Registration/ designation	Agreement or other legislation
Newfoundland			
Provincial Historic Sites	(also)	19	
Registered Historic Sites		4	
Registered Heritage Structures		35	
St. John's Municipal Heritage Areas			2 areas
Local Heritage Agency Administration	10+		53 buildings
Prince Edward Island			
PEI Heritage Foundation	3		
Charlottetown Historical Preservation Area			308 buildings/1 area
Local Heritage Agency Administration	5+		
Nova Scotia			
Provincial Historic Sites	20		
Special Places			3
Special Commissions			1 village
Provincial Registered Properties		115	
Municipal Registered Properties		600+	
Local Heritage Agency Ownership	34		
New Brunswick			
Protected Provincial Historic Sites	(some also)	22	
Municipal Heritage Areas			3 areas
Heritage Agency Administration	18		
Quebec			
Classified Cultural Property		494	
Recognized Cultural Property		86	
Heritage Districts		9	
Municipal Citation		46	
Municipal Sites		7	
Administration as Cultural Heritage Facilities	69	(+17 listed above)	
Ontario			
Ontario Heritage Federation Properties	28	(also)	
Ontario Heritage Foundation Heritage Easements		134	
Municipal Heritage Designation		2 500+	
Heritage Conservation Districts		20	
Provincial Parks	19		(also)
Tourism and Recreational Sites	8+		(also)
Conservation Authorities	15+		(also)
Local and Heritage Agencies	166		
Manitoba			
Provincial Historic Parks	4	(+5 included below)	
Provincial Heritage Sites		51	
Municipal Heritage Sites		44	
Winnipeg Landmark Heritage Structures			150 buildings
Local Heritage Agency Administration	48+	(+4 included above)	
Provincial Parks	18		(also)

(Continued on next page)

TABLE 7.8 (CONT'D)

Jurisdiction	Ownership	Registration/ designation	Agreement or other legislation
Saskatchewan			
Provincial Historic Sites	(also)	8	
Provincial Historic Parks	9		(also)
Provincial Heritage Property		30	
Municipal Heritage Property		497	
Local Heritage Agency Administration	108	(+35 included above)	
Provincial Parks	33+		(also)
Alberta			
Provincial Historic Sites	(also)	15	
Provincially Designated Sites		164	
Registered Historic Resources		107	
Municipal Historic Resources		3+	
Local Heritage Agency Administration	53+		
Provincial Parks	8		(also)
British Columbia			
Provincially Designated Sites	(some)	62	
B.C. Heritage Trust Properties	2	(also)	
Municipal Designated Heritage Buildings		507	
Municipal Heritage Zones			22
Provincial Historic Parks	6	(+1 also)	(4 also)
Provincial Parks	100		(also)
Administration by Local Government and Heritage Agencies	179	(+6 included above)	
Yukon			
Territorial Historical Parks	1		
Dawson Historic Area			1 area
Local Heritage Agency Administration	2		200 buildings
Northwest Territories			
Territorial Historic Sites	5	(also)	
Territorial Heritage Sites	3		
Local Heritage Agency	6		
Federal			
National Historic Sites	113	(also)	
Heritage Places			2
Classified Federal Heritage Buildings	(also)	90	
Registered Federal Heritage Buildings	(also)	368	
Total protected resources	**1093** +	**6037** +	**746** = **7876**[a]

[a] Although this figure may be useful, it is the first time such a listing has been made, and it is possible some omissions have been made. The "resources" described are very uneven in qualitative type. Some facilities listed as one number are very comprehensive: for example, 18 "resources" are listed for Manitoba Provincial Parks. This listing is for 18 parks containing over 719 individual resource sites. Historic sites and city listings also tend to be of this type.

Notes: Cultural resources in the environment are listed by jurisdiction, and within jurisdictions by a title that conforms as closely as possible to the name by which they are described within that jurisdiction.

When sites are protected by more than one means (i.e., legislative designation and ownership), the number of resources has been listed under the heading that invokes the major form of protection, and an "(also)" listing has been placed in the secondary category. This has been done in an effort to maintain a representative balance in the overall number of sites under discussion: i.e., to ensure each site is counted only once in total figures.

The use of the term "designated" varies considerably in its application on this chart. For purposes of listing these resources, any resource that has received legal acknowledgement that it requires a second assessment — i.e., assessment beyond the initial environmental review process — is considered "protected," even though, as in the case of Saskatchewan's Registered Heritage Buildings, its recognition may not be registered against the title providing long-term protection, or, as in the case of Alberta's Registered Heritage Resources, it may not have more than a 90-day delay associated with its second review. On the opposite extreme, only 22 of New Brunswick's 38 Provincial Historic Sites have been placed in this category because this is the only group for which either a process ensuring secondary review exists or the minister is empowered to interfere with ongoing activity. The 16 sites not included under the "designated" listing above are not included on this list unless they are owned by agencies sympathetic to their heritage value and are listed under ownership with that group. In short, recognition of these sites as resources of provincial importance implies moral responsibility but does not evoke any answerability or scrutiny and is not considered sufficient to constitute protection: they are, therefore, not included in a discrete category on the above chart, and they may not be listed at all unless they are eligible for listing under another heading.

Source: Carter (1990).

but which might provide a basis for analysis of protection of such sites. The Canadian Parks Service maintains the Canadian Inventory of Historic Buildings, a computerized listing of almost 200 000 buildings built before 1914. Similar inventories exist at other levels; what is missing to date is some form of coordination of all these data.

Viewed from a national perspective, the development of these approaches to heritage is at an early stage. However, it is an important beginning if we are to manage our living environment in an integrated way, working from a common vision. And the successful functioning and survival of our protected areas depend to a great extent on how well we manage the environment that surrounds them.

Designated sites

Some programs in Canada designate significant sites without necessarily offering formal protection (although protection often follows through other programs or initiatives). The Canadian Heritage Rivers System, for example, is a cooperative program established in 1984 by the federal, provincial, and territorial governments. The objective of the system is to give national recognition to important rivers of Canada and to encourage long-term management that will preserve their natural, historical, and recreational values. Although designation as a heritage river does not confer any special legal protection to the area in question, this designation is often reinforced by provincial park status. For example, Ontario, Manitoba, and Newfoundland have established waterway parks to protect outstanding rivers. Not all waterway parks are necessarily heritage rivers, nor are all heritage rivers waterway parks. To date, there are 13 designated rivers in the Canadian Heritage River System, and 6 more have been nominated. Collectively, they comprise about 4 114 km of riverine habitat (N. Coomber, Environment Canada, Canadian Parks Service, personal communication).

International protected area programs in Canada

A number of designations are conferred by international conservation networks and agencies to recognize and promote conservation of areas of global significance. Several natural and cultural features in Canada have been recognized by international programs such as the World Heritage Convention, the Man and the Biosphere Programme, the Ramsar Convention, and the Western Hemisphere Shorebird Reserve Network (Table 7.9).

World Heritage Convention

The Convention on the Protection of the World Cultural and Natural Heritage was adopted by the 1972 General Assembly of the United Nations Educational, Scientific and Cultural Organization (UNESCO). It recognizes the obligation of all nations to protect areas that are of such unique value that they form part of the heritage of all humankind. The Convention has been signed by 115 states. Technical advice is provided by the World Conservation Union (IUCN), for natural areas, and the International Council of Monuments and Sites, for cultural sites.

Designation as a World Heritage Site does not confer any special legislative status. However, a site must be guaranteed long-term protection before it can be so designated. As with other international designations, formal protection of a World Heritage Site is a responsibility of the country in which the site is located. The World Heritage Committee provides limited financial and technical aid to help ensure protection in special cases.

To date, 338 world heritage sites (245 cultural, 80 natural, and 14 with both cultural and natural significance) have been designated in 71 nations; 10 are in Canada, an increase of 2 since 1985 (see Table 7.9).

Man and the Biosphere Programme

In the early 1970s, as a follow-up to the International Biological Programme, the General Conference of UNESCO launched an international ecological

TABLE 7.9

Internationally recognized heritage sites, 1990

International designation	Sites
World heritage sites	**natural sites** • Gros Morne National Park, Newfoundland • Kluane National Park Reserve, Yukon • Wood Buffalo National Park, Alberta/Northwest Territories • Canadian Rocky Mountains (Banff, Jasper, Kootenay, and Yoho National Parks and Mt. Assiniboine, Mt. Robson, and Humber Provincial Parks), Alberta/British Columbia • Dinosaur Provincial Park, Alberta • Nahanni National Park Reserve, Northwest Territories **cultural sites** • Anthony Island, British Columbia • Head-Smashed-In Buffalo Jump, Alberta • L'Anse Aux Meadows National Historic Park, Newfoundland • Historic District of Quebec City, Quebec
Biosphere reserves	• Waterton Lakes, Alberta • Riding Mountain, Manitoba • Long Point, Ontario • Niagara Escarpment, Ontario • Mont St. Hilaire, Quebec • Charlevoix, Quebec
Ramsar sites	• Grand Codroy Estuary, Newfoundland • Malpeque Bay, Prince Edward Island • Chignecto, Nova Scotia • Musquodoboit Harbour Outer Estuary, Nova Scotia • Southern Bight–Minas Basin, Nova Scotia • Mary's Point, New Brunswick • Shepody Bay, New Brunswick • Cap Tourmente, Quebec • Baie de l'Île Verte, Quebec • Lac Saint-François, Quebec • Long Point, Ontario • St. Clair, Ontario • Polar Bear Provincial Park, Ontario • Southern James Bay, Ontario • Point Pelee National Park, Ontario • Delta Marsh, Manitoba • Oak–Hammock Marsh Wildlife Area, Manitoba • Last Mountain Lake, Saskatchewan • Quill Lakes, Saskatchewan • Whooping Crane Summer Range, Alberta and Northwest Territories • Peace–Athabasca Delta, Alberta • Hay–Zama Lakes, Alberta • Beaverhill Lake, Alberta • Polar Bear Pass, Northwest Territories • Queen Maud Gulf, Northwest Territories • Rasmussen Lowlands, Northwest Territories • McConnell River, Northwest Territories • Dewey Soper, Northwest Territories • Alaksen, British Columbia • Old Crow Flats, Yukon
Western Hemisphere Shorebird Reserves	• Shepody Bay, New Brunswick • Minas Basin, Nova Scotia

program called Man and the Biosphere. One of its long-term goals is to create an international network of biosphere reserves that will represent the world's major ecological systems and different patterns of human use and adaptation to them.

Selection of biosphere reserves is based upon their representing particular biogeographical provinces. Each reserve includes a protected core of relatively undisturbed land, together with areas that demonstrate how such lands are being managed to meet human needs. While conservation of representative features is a major objective of such reserves, so is long-term research and environmental monitoring. Comparative studies of protected and utilized zones lead to improved resource management practices, rehabilitation, and documentation of changes arising from human activities.

Canada currently has six biosphere reserves (Table 7.9), an increase of four since 1985. Nevertheless, there are large gaps in Canada's biosphere reserve network. A target of nine more biosphere reserves has been recommended for Canada, including five in the North, to add to the coverage of the world's biogeographic provinces (Canadian Commission for the United Nations Educational, Scientific and Cultural Organization 1987).

Ramsar Convention

The Convention on the Conservation of Wetlands of International Importance, drafted in Ramsar, Iran, in 1971, acknowledges the value of wetlands as areas of international biological significance. By June 1990, the Convention had designated 488 sites. Of these, the 30 in Canada cover 130 000 km^2 of wetland habitat, the largest area of designated Ramsar wetlands of any country. This is not surprising, as Canada has 24% of the world's wetlands. Although designation in itself provides no enforceable protection for the wetlands, most of these are protected by existing federal or provincial legislation.

Western Hemisphere Shorebird Network

This cooperative program of government and private organizations recognizes and protects essential staging areas for migratory shorebirds. Two arms of the Bay of Fundy, Shepody Bay and Minas Basin, have been designated in Canada and are twinned with sites in Surinam, South America, because of their importance to the Semipalmated Sandpiper (see Chapter 20).

ECOLOGICAL INTEGRITY OF PROTECTED NATURAL AREAS

Drawing a boundary around a piece of land does not ensure its long-term protection, regardless of its status. Long-term protection depends upon whether the chosen unit was viable initially, how well it has been managed to perpetuate its conservation values, and compatibility of adjacent land uses. The ecological integrity of a natural area is what determines its capacity to withstand internal and external stresses. The term implies that an area incorporates natural ecosystems that are self-sustaining and self-regulating, with a full complement of species, complete food webs, and naturally functioning ecological processes.

How well are we maintaining the ecological integrity of existing parks, reserves, and other natural sites after more than a century of managing protected areas? We just do not know. But there are disturbing indications that things are not what they used to be.

Most, if not all, protected area ecosystems have been markedly changed by human activity. For example, in tiny Point Pelee National Park, 43% of the plant species are exotics, not native to the park (Environment Canada 1987). Exotic species abound in other national and provincial parks as well. Some were introduced accidentally, many intentionally. Ornamental plants brightened gardens around staff housing; exotic game species were introduced to improve the quality of fishing and hunting. These exotic species compete for suitable habitat with native biota, thereby disrupting the original ecosystem.

No comprehensive analysis of the ecological health of Canada's protected areas exists, but it is needed. A 1980 survey of threats to national parks in the United States demonstrated the value of such an agenda for remedial action (National Parks Service 1980).

Most protected natural areas in Canada are too small to maintain their biological diversity in today's rapidly changing world. A survey of parks in western North America showed that only the four contiguous mountain parks (Banff, Jasper, Yoho, and Kootenay) had not yet experienced species loss (Newmark 1987). Wide-ranging mammals such as grizzly bear, caribou, and wolf have critical habitat requirements that are not totally included even within the boundaries of these parks (Dueck 1990).

Protected natural areas are becoming biogeographic islands, their integrity at risk from encroachment by consumptive land uses, such as logging, agriculture, oil and mineral development, power dams, and industrial processes on their boundaries. Kejimkujik National Park, in Nova Scotia, was placed on the IUCN endangered wilderness list because of the effects of acid rain. Ontario's wilderness park in Temagami was listed because of the potential impact of proposed logging activities (H. Eidsvik, personal communication).

Global climatic change will inevitably influence protected areas, resulting in forest dieback and species migration and conceivably altering habitat to the point that parks or reserves no longer contain the ecosystems they were created to protect. Such effects are expected to be most severe in sensitive areas like the boreal forest–grassland transition zone represented by Prince Albert National Park (see Chapter 22).

Some protected areas, such as national and provincial parks, face the challenge of a dual mandate: to protect ecosystems and to provide recreational opportunities for visitors. The dilemma is how to maintain ecological integrity while fulfilling both objectives.

In recent years, tourism has increased in most national parks. For example, the four mountain parks cited above receive about 10 million visitors per year. Their supposed wilderness territory is transected by a four-lane highway and two transcontinental railway corridors. Four towns are located within their boundaries, with overnight accommodation for about 15 000 visitors. And pressures are mounting to expand hotels, downhill ski facilities, convention centres, and condominiums still further.

Although intensive recreational facilities cover only a small percentage of these parks, they do affect their ecological integrity. Most of the visitor facilities are located in river valleys, the most productive of wildlife habitats. Alpine ski facilities are located on fragile alpine meadows. The ecological impacts of recreational facilities extend beyond their physical presence; the environment must also assimilate the wastes generated by the rapidly increasing population of visitors. In fact, visitor impacts are the most frequently mentioned natural resource management problem in national parks (Irvine 1988).

To a considerable degree, the effects of overuse and poor planning can be offset by further, deliberate interventions. Trails can be hard surfaced; areas can be fenced; access can be controlled or channelled. Around Lake Louise, in Banff National Park, hardened trail surfaces may have reduced the quality of wilderness experience for some visitors, but it has allowed a substantial increase in visitation without degrading the resources beyond the levels chosen in the site design objectives. At Lake O'Hara in Yoho National Park, visitors were fewer in number, but a fragile environment was still suffering damage. The solution in that case has been to limit access, relocate major features, such as the campground, away from sensitive meadows, and begin major rehabilitation programs in the damaged areas.

Managers of protected areas must plan to ensure that visitor activities are appropriate, that visitor densities are not too high, and that ecosystems retain their integrity. Certain land-use activities can result in detrimental ecological effects, especially if the status of the protected area permits extractive activities that involve major habitat disturbance. For example, managed commercial logging is allowed in large areas of Algonquin Provincial Park, whereas only small areas are zoned for strict protection. The long-term impact on park values has not been confirmed, but there is concern that the ecological integrity of the park is being reduced by the industrial conversion of forest stands.

Zoning is another mechanism used to provide for an acceptable level of visitor use in a manner consistent with resource protection. The Canadian Parks Service uses a five-class zoning system for management — from preservation to recreation. In Banff National Park, nearly all development is located within 1% of the park; 97% of the park is in the wilderness zone. Critics of Banff's zoning, however, claim the wilderness zones do not always protect the most vulnerable habitats (Bailey 1990).

Fiscal restraint has forced protected area agencies to devise innovative means of carrying out their mandates: volunteer programs, cooperating associations, and agreements with other government agencies and universities for research in, or for, protected areas. It has accelerated the integration of parks regionally and with local communities, and it has helped to dispel the old fortress mentality of protected areas as independent enclaves completely isolated from adjacent lands.

Other factors can also be very important vis-à-vis the long-term maintenance of an area's ecological integrity. Boundaries of parks established by legislation and especially those established by orders-in-council can easily change shape or size depending on the political climate. For example, Waterton Lakes National Park was halved in 1921 to accommodate provincial land demands; three small parks in the Prairies were abolished after the recovery of the pronghorn antelope population that they were designed to protect; Ghost Wilderness Area in Alberta was once three times its present size; and Cape Breton Highlands has been diminished twice, once to allow mining, and again for hydroelectric development (Bailey 1990; Nikiforuk 1990).

These stresses on the natural environment within and outside protected area boundaries have serious implications for how protected areas should be managed. Not only must areas be large enough to preserve ecological diversity in the long term, but good planning within boundaries and sound stewardship and monitoring programs outside boundaries must be practised. Clearly, more active long-range management programs are required. Regional strategies and greater cooperation with agencies involved in land management beyond protected area boundaries are needed, along with the establishment of buffer zones between protected areas and adjacent unprotected lands (Bonnicksen 1988).

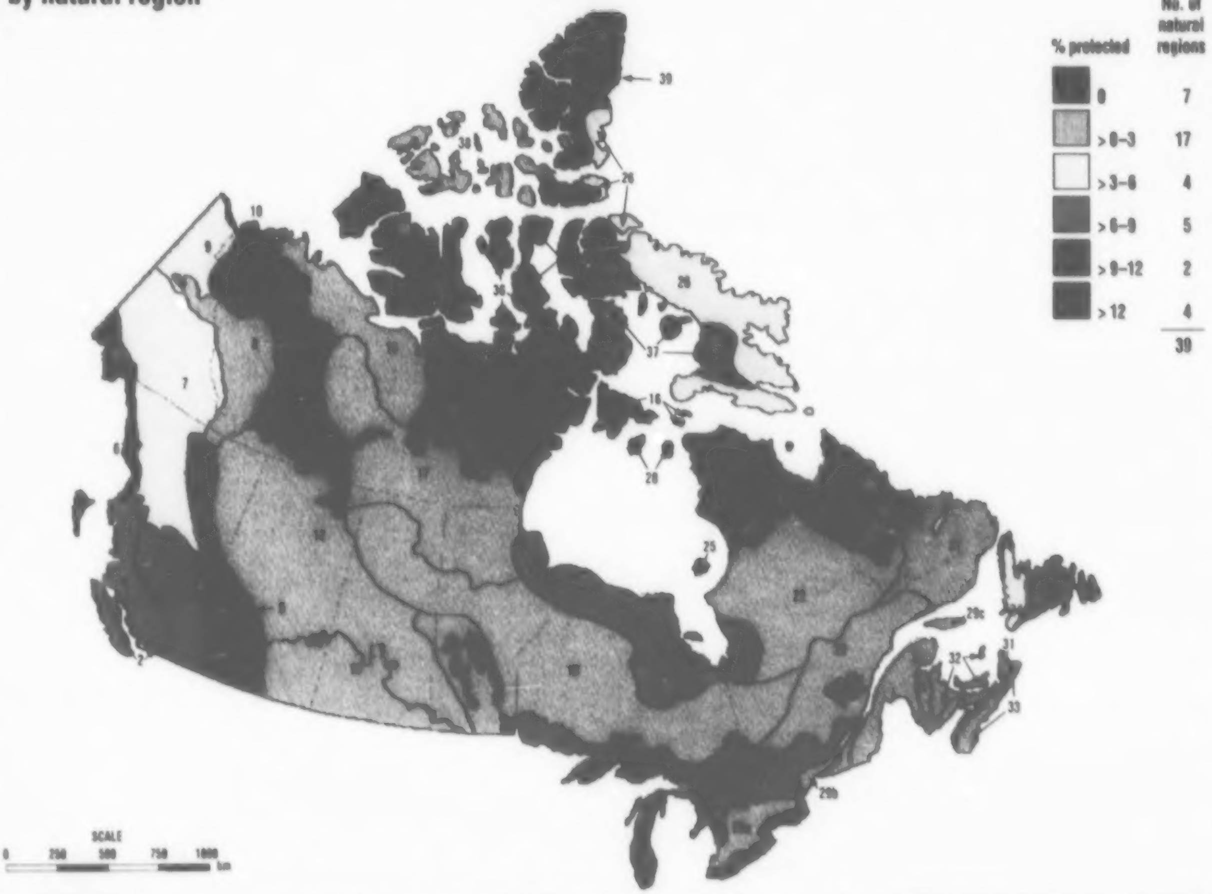
Few protected area agencies in Canada have consistent environmental monitoring programs. Most inventory and monitoring programs for protected areas require updating. To date, there is little research to indicate how well protected areas meet established conservation mandates, or even how to measure this criterion of effectiveness.

To manage and preserve protected areas effectively, and to succeed in implementing the concept of sustainable development, we have to understand natural ecosystems. We cannot manage what we do not understand. Protected areas in Canada face many threats, and lack of knowledge must be considered one of these (Pritchard 1989).

Several jurisdictions have taken specific actions to enhance the ability of protected areas to maintain natural features and ecological processes that sustain-life support systems. For example, in 1988, the Ontario govern-

FIGURE 7.4

Protected space (IUCN categories I and II) by natural region



% protected	No. of natural regions
■ 0	7
▨ > 0–3	17
□ > 3–6	4
■ > 6–9	5
■ > 9–12	2
■ > 12	4
	39

Western Mountains

1 Pacific Coast Mountains
2 Strait of Georgia Lowlands
3 Interior Dry Plateau
4 Columbia Mountains
5 Rocky Mountains
6 Northern Coast Mountains
7 Northern Interior Plateaux and Mountains
8 Mackenzie Mountains
9 Northern Yukon Region

Interior Plains

10 Mackenzie Delta
11 Northern Boreal Plains
12 Southern Boreal Plains and Plateaux
13 Prairie Grasslands
14 Manitoba Lowlands

Canadian Shield

15 Tundra Hills
16 Central Tundra Region
17 Northwestern Boreal Uplands
18 Central Boreal Uplands
19a West Great Lakes–St. Lawrence Precambrian Region
19b Central Great Lakes–St. Lawrence Precambrian Region
19c East Great Lakes–St. Lawrence Precambrian Region
20 Laurentian Boreal Highlands
21 East Coast Boreal Region
22 Boreal Lake Plateau
23 Whale River Region
24 Northern Labrador Mountains
25 Ungava Tundra Plateau
26 Northern Davis Region

Hudson Bay Lowlands

27 Hudson–James Lowlands
28 Southampton Plain

St. Lawrence Lowlands

29a West St. Lawrence Lowland
29b Central St. Lawrence Lowland
29c East St. Lawrence Lowland

Appalachian

30 Notre Dame–Megantic Mountains
31 Maritime Acadian Highlands
32 Maritime Plain
33 Atlantic Coast Uplands
34 Western Newfoundland Island Highlands
35 Eastern Newfoundland Island Atlantic Region

Arctic Lowlands

36 Western Arctic Lowlands
37 Eastern Arctic Lowlands

High Arctic Islands

38 Western High Arctic Region
39 Eastern High Arctic Glacier Region

Source: Environment Canada, State of the Environment Reporting, National Conservation Areas Data Base, 1991.

ment prohibited mining and sport hunting in all provincial wilderness parks and nature reserves. Saskatchewan prohibited any new mining initiatives in provincial parks.

In 1988, Parliament approved a number of amendments to the *National Parks Act* to improve the ability of the Canadian Parks Service to protect national park resources. The act now directs the government to develop management plans for each park and to place a priority on the maintenance of ecological integrity. The management plans are tabled in Parliament and reviewed every five years, and changes must be tabled in the House of Commons. Other amendments include: a dramatic increase in fines for poaching (up to $150 000); the ability to designate wilderness areas by regulation; and prohibition of construction of new energy transmission corridors through national parks without the approval of Parliament.

COMPLETING PROTECTED AREAS SYSTEMS

Wild lands have been defined as areas of at least 10 km in diameter where there are neither roads nor settlements. Excluding Antarctica, almost 20% of the world's remaining wild lands are in Canada (McCloskey and Spalding 1989). Between 65 and 72% of Canada is still wild. Nevertheless, since the mid-1970s, wild areas in Canada have been reduced by 4%, an area larger than that of all Canada's national parks combined (Chipeniuk 1990). This may not sound alarming, but most of that loss has been concentrated along the southern fringe of the large contiguous wild areas — the part most accessible to the people of Canada. In the last decade, wild areas have retreated northward more than 100 km from Montreal and Toronto and have largely disappeared from the Maritimes, the Prairies, and the southern portions of all provinces.

Across northern Canada, which many Canadians still regard as an empty wilderness, land-use commitments are foreclosing protected area options on a massive scale. Long-term forest management agreements have been signed for large areas of Alberta, Quebec, and Manitoba, as well as parts of Saskatchewan. Proposed hydroelectric developments in the Hudson Bay and James Bay basin would inundate areas comparable in size to Lake Erie. Aquaculture leases are being granted along extensive portions of east and west coasts. Aboriginal land claim settlements in Yukon and the Northwest Territories have important implications for future decisions about protected areas. Even if the lands and waters are not exploited immediately, all these commitments are diminishing the flexibility to establish protected areas as an integral component of planning for the total landscape.

In many parts of Canada, the opportunity to establish protected natural ecosystems has already vanished. Only scattered remnants of southern Ontario's Carolinian forest are left; the once-vast prairie grasslands remain only as isolated relics of their former expanse; less than 3% of the west coast rain forest has been left undisturbed (Thompson 1987); and the virgin Acadian forests of the Maritimes are almost completely gone.

Of the various systems of protected areas in Canada, none is complete. To protect vanishing ecosystems, and to meet Canada's Green Plan 12% target for protecting representative samples of species and ecosystems, the 13 major jurisdictions responsible for protected areas will have to take decisive action.

Perspective based on the natural regions framework

Action to complete plans for protected areas systems has been stimulated by the Endangered Spaces campaign, launched in 1989 by World Wildlife Fund Canada and the Canadian Parks and Wilderness Society. More than 200 000 Canadians have signed the Canadian Wilderness Charter, mission statement for the campaign, which calls on governments to establish at least one representative protected area in each of Canada's natural regions by the year 2000.

On land, the National Parks System is just over 50% complete, with national parks in 21 of 39 natural regions. Marine regions are not faring as well, with 2 of 29 regions represented by a marine park. Under Canada's Green Plan, the federal government is committed to establishing at least five new terrestrial national parks by 1996 and to completing the system by the year 2000. It is estimated by the Canadian Parks Service that, once completed, the National Parks System could occupy between 2.8 and 3.4% of the Canadian landscape, compared with the current 1.8%.

Of the 18 terrestrial regions that lack national parks, 6 have provincial parks, 5 others have bird or game sanctuaries, and, in 4 others, potential national park sites have been identified (Environment Canada 1990). In other words, 33 of the 39 regions currently have at least one national park or equivalent protected area, and preliminary work has been done for the establishment of protected areas in several of the remaining regions.

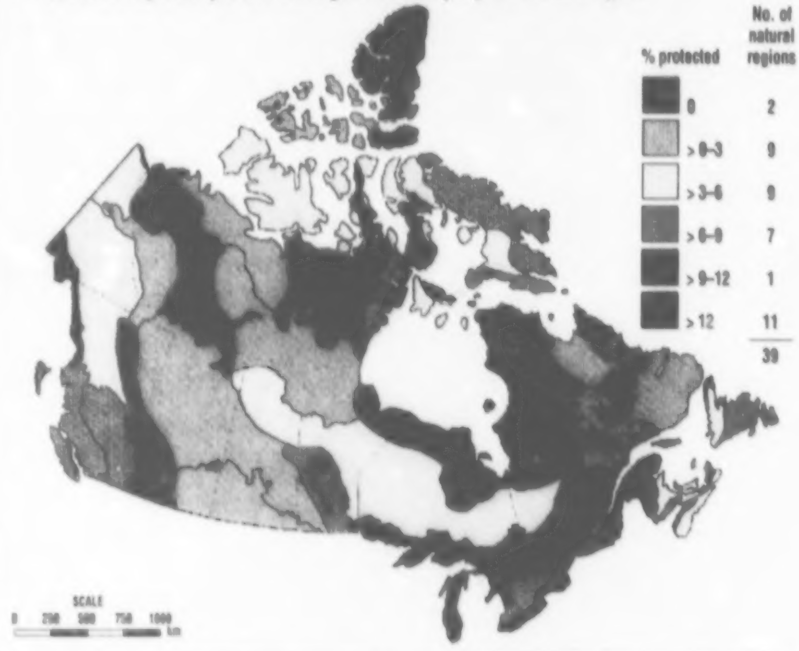
The number of parks can be somewhat misleading, however, unless we take the size of the protected areas into consideration. Many of the natural regions are, in fact, represented by protected areas that are too small, on their own, to preserve a reasonably complete sample of the ecological diversity of the region.

Figures 7.4 and 7.5 show the percentage of each natural region that is protected. These figures are used for illustration purposes only. The Green Plan target serves as a useful reference point. However, that goal, as stated, is not necessarily to protect 12% of each natural region, but to protect a representative sample of each region within a system that will encompass 12% of Canada's total area. The size of protected areas is nevertheless an important consideration, as discussed earlier in this chapter.

Figures 7.4 and 7.5 attempt to illustrate progress that governments are making towards this protected areas goal. Figure 7.4 includes only those areas that enjoy protection that is equal or superior to that in national parks (IUCN

FIGURE 7.5

Protected space (IUCN categories I–V) by natural region



Note: Refer to Figure 7.4 for natural region names.

Source: Environment Canada, State of the Environment Reporting, National Conservation Areas Data Base, 1991.

categories I and II). Figure 7.5 includes these areas plus less strictly protected areas where habitat manipulation and resource extraction may be permitted (IUCN categories I–V). In both cases, sites that are designated but not legally protected are not included on the maps. These sites would include parts of protected landscapes and sites without a conservation focus (mostly small), such as boat ramps, picnic areas, and heritage buildings. The portions of these categories that are classified as parks or reserves, however, are included. Data on lands conserved by private sector groups are not included on the maps.

Seven of the 39 natural regions contain no areas protected at IUCN level I or II; in another 17 natural regions, between 0 and 3% receive strict protection. These 24 regions together represent about two-thirds of Canada. Only 4 natural regions have greater than 12% of their area strictly protected (Fig. 7.4). When all sites in IUCN categories I–V are considered, the overall picture is a little more encouraging. Eleven natural regions have more than 12% of their territory under some degree of protection; these regions cover almost a third of the country. Nevertheless, 20 natural regions representing more than half of Canada have less than 6% of their area in parks, reserves, and other protected space (Fig. 7.5). Although all categories of protected land contribute to the achievement of environmental goals, for research purposes, and for the maintenance of full species diversity, more strictly protected areas are required.

Figures 7.4 and 7.5 clearly illustrate that there are significant gaps in the protected areas network, where action is urgently needed. Even when less strictly protected areas are included, certain regions are seriously underrepresented.

Marine regions

Canada has the longest coastline (244 000 km) of any nation in the world. Yet our protection of marine ecosystems lags far behind that of terrestrial areas. Only two of the Canadian Parks Service's marine regions are represented by federal parks — Georgian Bay and West Vancouver Island Shelf. The remaining 27 regions currently have no protection under the federal parks system (Fig. 7.6). Agreements to create two more marine parks have recently been negotiated — Saguenay Marine Park at the confluence of the Saguenay and St. Lawrence estuary and a 3 000-km^2 marine protected area in association with South Moresby Island/Gwaii Haanas National Park Reserve. Two other marine parks have been proposed — West Isles in the southern Bay of Fundy and another in Lancaster Sound. The Lancaster Sound proposal is currently on hold because of local concerns regarding resource harvesting. Several coastal, national terrestrial parks (Ellesmere Island, Pacific Rim, Auyuittuq, Forillon, and Kouchibouguac) include marine components totalling over 4 000 km^2. The federal government, through Canada's Green Plan, is committed to establishing three national marine parks by 1996 (including South Moresby and Saguenay) and three more by the year 2000.

Establishing marine protected areas is difficult. Many jurisdictions share responsibility for ocean resources, and there is little legislation enabling the protection of marine resources (Lien 1989). National marine parks are recognized under the recently revised *National Parks Act*. Marine protected areas have also been established under the *Canada Wildlife Act* and under provincial ecological reserve legislation. These areas are not included in Figure 7.6.

Canadian Shield and arctic lowlands

Under the Canadian Parks Service framework, the Canadian Shield and arctic lowlands are subdivided into 14 natural regions. In all but two of them, less than 3% of the territory is strictly protected (Fig. 7.4). These regions of the Northwest Territories, Manitoba, Quebec, and Labrador are among the most vulnerable and unprotected in

Canada. Nevertheless, significant changes are occurring as oil, mineral, hydroelectric, and other resources are developed and aboriginal land claims settled. Options for establishing protected areas in the North are disappearing, and action needs to be taken quickly to establish a comprehensive network of protected areas.

Of 136 "Special Areas in the North" identified in 1982 by Environment Canada as deserving protection (Environment Canada 1982), few have been acted upon. Only one national wildlife area, Polar Bear Pass, and 16 migratory bird sanctuaries have been established north of 60°. The Canadian Wildlife Service has identified over 80 sites in the North, mainly for the protection of waterfowl and seabird populations. Nineteen of these have been selected for future protection as migratory bird sanctuaries. Prince Leopold Island will likely be the next area protected. Many areas of critical importance to marine fauna and terrestrial wildlife other than birds have been identified. Protection of such areas requires jurisdictional cooperation.

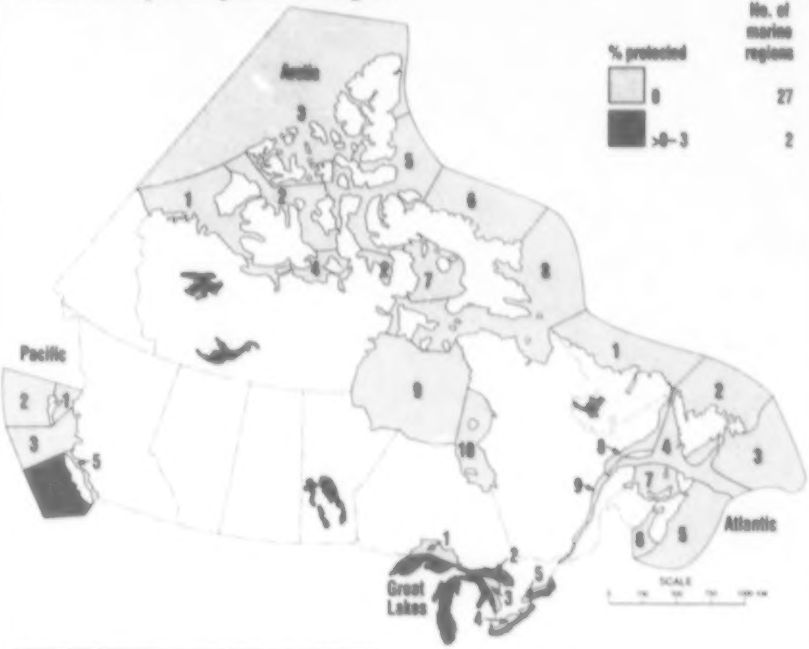
Local communities and the territorial governments are identifying natural areas and cultural features that should be placed within a network of protected areas. A plan with an extensive protected areas component has been completed for the Lancaster Sound region, and the Mackenzie delta–Beaufort Sea region has a draft plan.

Comprehensive land claims settlements between aboriginal people and the federal government are at various stages of completion. Each claim outlines terms and a process for establishing and managing national parks and protected areas within the claim area. Under the claim of the Tungavik Federation of Nunavut, in the eastern Arctic, the federal government is committed to establishing at least three national parks three years after the agreement is approved by Parliament.

The boreal forest regions are the areas where wild lands are now disappearing at the greatest rate, as a result of extensive logging activity (see Chapter 26). At current rates of cutting, large contiguous wild areas will disappear in the next 20 years. There are few large protected areas within the commercially valuable boreal forests of Canada.

FIGURE 7.8

Protected space by marine region



Pacific Ocean

1 Hecate Strait
2 West Queen Charlotte Island
3 Queen Charlotte Sound
4 West Vancouver Island Shelf
5 Strait of Georgia

Great Lakes

1 Lake Superior
2 Georgian Bay
3 Lake Huron
4 Lake Erie
5 Lake Ontario

Atlantic Ocean

1 North Labrador Shelf
2 South Labrador Shelf
3 Grand Banks
4 Laurentian Trough
5 Scotian Shelf
6 Bay of Fundy
7 Magdalen Shallows
8 North Gulf Shelf
9 St. Lawrence River Estuary

Arctic Ocean

1 Beaufort Sea
2 Viscount Melville Sound
3 Northern Arctic
4 Queen Maud Gulf
5 Lancaster Sound
6 Eastern Baffin Island Shelf
7 Foxe Basin
8 Davis and Hudson Straits
9 Hudson Bay
10 James Bay

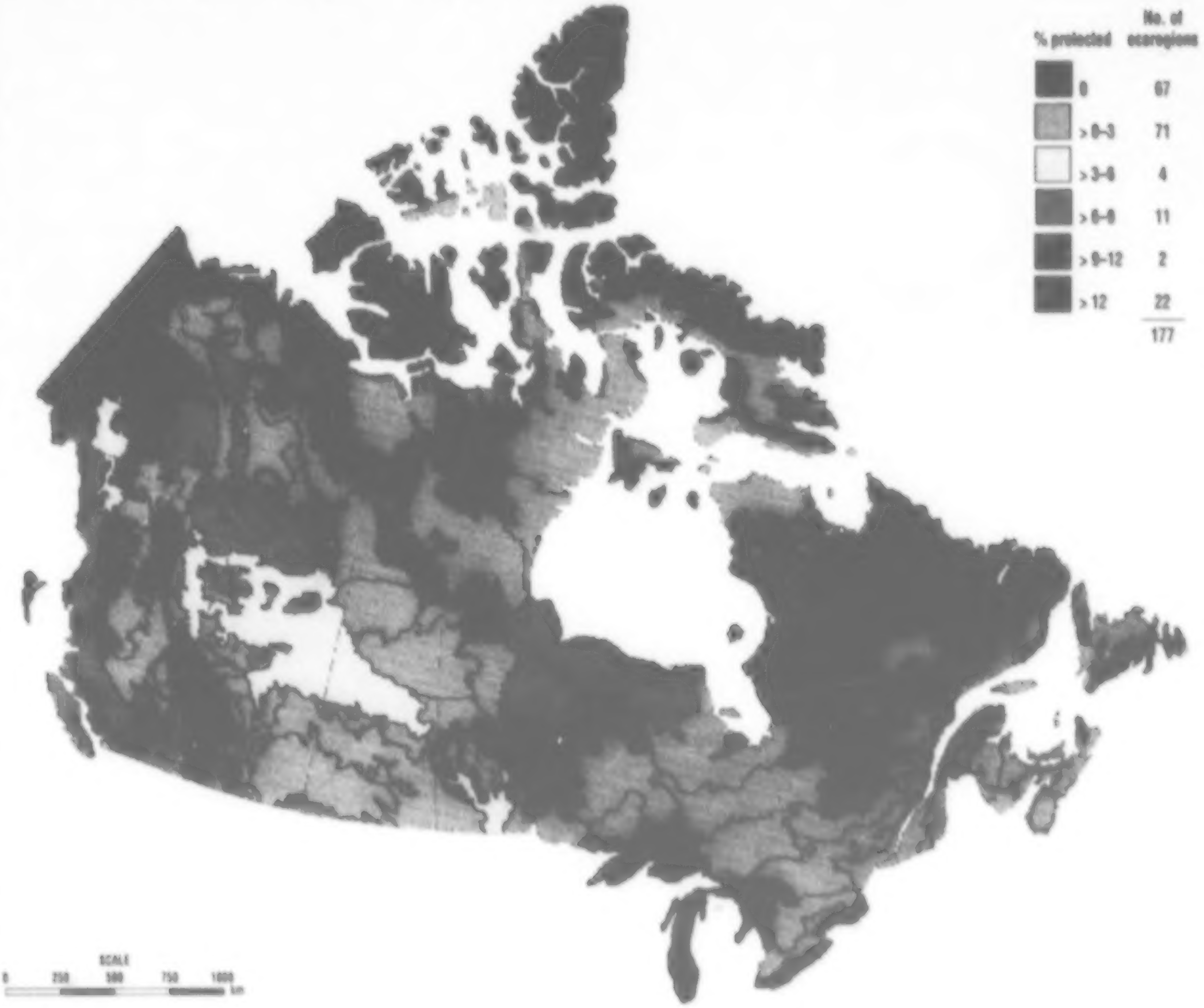
Source: Environment Canada, State of the Environment Reporting, National Conservation Areas Data Base, 1991.

Prairie grasslands

Over the last 100 years, the prairie grasslands natural region has been transformed from a wild area with diverse flora and fauna to one of the world's most extensively modified areas. More than 99% of tall-grass prairie, 82% of short-grass prairie, 90% of fescue grassland, and 76% of mixed-grass prairie and aspen parkland have been converted to agricultural uses (World Wildlife Fund Canada 1989). Not surprisingly, several of Canada's

FIGURE 7.7

Protected space (IUCN categories I and II) by ecoregion



Source: Environment Canada, State of the Environment Reporting, National Conservation Areas Data Base, 1991.

threatened and endangered animal species are native to this profoundly altered region, of which less than 3% receives any protection (Fig. 7.5). Two military bases, Suffield and Wainwright, contain the best examples of relatively undisturbed prairie habitat.

Progress is being made towards the establishment of Grasslands National Park, which will protect 906 km² of grassland in southern Saskatchewan. This park is an example of the trend for the federal government to share the responsibility for conservation with other governments and the public. Saskatchewan maintains ownership of watercourses in the park and will manage them to national park standards. The Canadian Nature Federation and the Nature Conservancy of Canada have established the Grasslands Trust Fund to solicit donations to purchase more land for preservation.

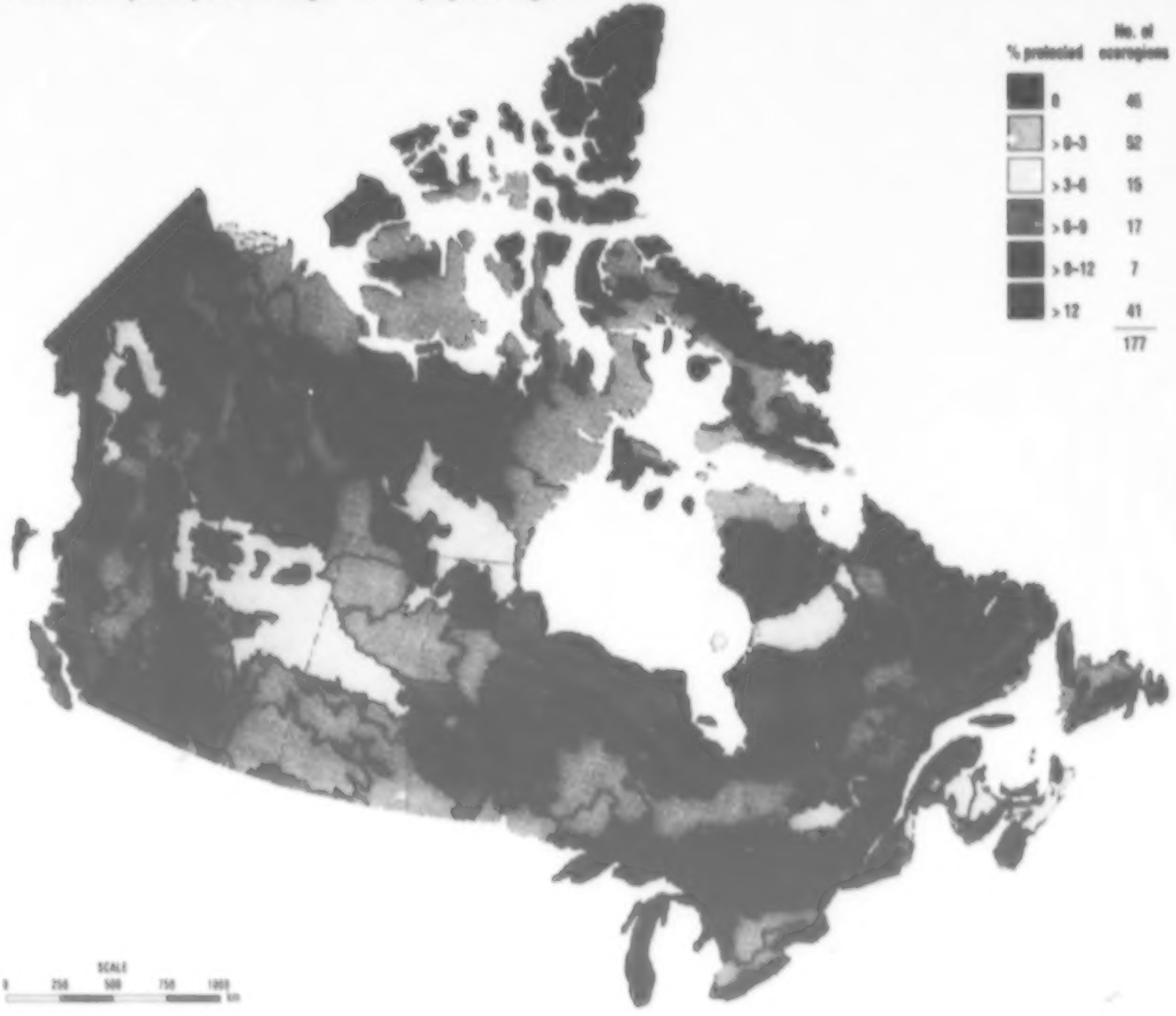
To protect the grasslands, World Wildlife Fund Canada has created the Prairie Conservation Action Plan. One of the plan's objectives is to establish protected areas that represent each of the four distinctive prairie grassland ecosystems (World Wildlife Fund Canada 1989).

St. Lawrence lowlands

Less than 3% of the St. Lawrence lowlands natural region is strictly protected (Fig. 7.4). This region includes southern Ontario and Canada's last remnants

FIGURE 7.8

Protected space (IUCN categories I–V) by ecoregion



Source: Environment Canada, State of the Environment Reporting, National Conservation Areas Data Base, 1991.

of the endangered Carolinian forest region. Most of this area has been converted into urban or agricultural use. Point Pelee National Park, representing the Carolinian portion of the west St. Lawrence lowlands subregion, is one of Canada's smallest, a mere 16 km², consisting mainly of marsh and sand spit. Provincial protected areas do not represent all of the region's ecosystems and are also too small to maintain ecological integrity.

It is in this region that private nonprofit organizations have had the greatest influence on the protection of remnant natural areas. Several sites, such as Mandaumin Woods, have been purchased outright by nonprofit groups; Backus Woods, the best mature stand of Carolinian forest remaining in Canada, is managed by the Long Point Region Conservation Authority, with financial assistance from the Ontario Heritage Foundation and input to the management plan from local naturalists' groups. The Ontario government has acted to protect the Rouge River valley, an important Carolinian site to the east of Toronto.

Perspective based on the ecoregions framework

Figures 7.7 and 7.8 use the same data as Figures 7.4 and 7.5, respectively, but present it in the ecoregions framework of the Canadian Ecological Land

TABLE 7.10

Progress towards completing protected areas systems

Jurisdiction	Natural regions mapped	Number of regions	Representation goals established	Committed to complete system by year 2000	No. (%) of natural regions represented in 1990
Newfoundland					
Prince Edward Island		7			
New Brunswick					
Nova Scotia	✓	9[a]			
Quebec	✓	43	✓		10 (23)
Ontario	✓	65	✓	✓	32 (50)
Manitoba	✓	12	✓	✓	5 (42)
Saskatchewan	✓	31	✓	✓	21 (68)
Alberta	✓	17	✓		3 (18)
British Columbia	✓	59	✓		28 (47)
Yukon	✓	13		✓	
Northwest Territories					
Federal	✓	39	✓	✓	21 (54)

[a] 9 natural regions and 34 subregions.

Source: World Wildlife Fund Canada (1990); A. Hackman, World Wildlife Fund Canada, personal communication.

Classification System. The figures show similar trends and gaps in the system as in the natural regions framework but on a more detailed scale. Figure 7.7 shows that 67 ecoregions (out of a total of 177) have no strictly protected areas; in 138 ecoregions (over three-quarters of Canada), less than 3% of the territory is strictly protected. Only 22 ecoregions have more than 12% of their territory strictly protected. When all sites receiving any degree of protection are analyzed (Fig. 7.8), there are 41 ecoregions (about one-fifth of the country) in which more than 12% of the area is protected, and 97 ecoregions where less than 3% of the area receives any protection.

The ecoregions framework, like the natural regions framework, shows the largest gaps in the protected areas system to be in the boreal, tundra, grassland, and lower arctic regions. The differences between the two frameworks are due to the size of the ecological regions. For example, under the Canadian Parks Service's natural regions framework, the Pacific coast mountains region includes South Moresby/Gwaii Haanas National Park Reserve. This puts the natural region in the 9–12% protected category (Fig. 7.4). Under the ecoregions framework, the same area includes all or part of 11 different units. The South Moresby Island ecoregion falls into the >12% category; the others receive varying degrees of representation, 0% to >12% (Fig. 7.7).

Provincial systems

The goal of protecting 12% of Canada within a network of representative protected areas requires action by the provinces and territories. Table 7.10 illustrates their progress. Ontario, Manitoba, Saskatchewan, and Yukon are committed to completing their protected systems by the year 2000. Seven provinces and one territory have mapped their natural regions, and six have set goals for representation of these regions in protected areas. Newfoundland, Prince Edward Island, New Brunswick, and the Northwest Territories have yet to map their natural regions and set targets for protected areas systems. Out of 256 natural regions defined to date by the provinces and Yukon, 99 are currently represented (World Wildlife Fund Canada 1990).

The growth of Ontario's parks system to 261 parks has been a highlight of parks system expansion in Canada. Over the past several years, Ontario's Provincial Parks System has largely been completed in terms of representing the province's biophysical diversity. Despite the slow growth of most provincial parks systems over much of the last decade, many provinces are moving ahead with plans to reorient provincial parks systems to better represent and protect biological and landscape diversity. Although progress has been made, many of the provincial protected areas are very small. For example, although Alberta has 61 provincial parks, 45 of them are less than 10 km^2, and only 2 are larger than 100 km^2 (Bailey 1990).

Despite the global significance of wilderness, few jurisdictions have a legislative mandate to protect wilderness areas. The provinces of Newfoundland, Ontario, Alberta, and British Columbia have passed wilderness legislation. The number of sites and total protected area by province are: Newfoundland, 2 sites, 3 965 km^2; Ontario, 37 sites, 618 km^2; Alberta, 4 sites, 5 607 km^2; British Columbia, 1 site, 1 315 km^2 (Hummel 1989; World Wildlife Fund Canada 1990). Under the *Forest Act*, British Columbia can establish wilderness areas, but mining is not prohibited within them. Ontario's *Wilderness Act* allows resource development in areas larger than 2.6 km^2.

Organizational frameworks have been established by the federal government, all provincial and territorial governments, and many Canadian municipalities to manage the protection of cultural heritage resources. However, resource inventories are incomplete. Only 6 of the 13 major government jurisdictions responsible for heritage administration in Canada have systems plans for assessing balance in resource representation (Carter 1990).

Other areas for priority action

It is important to point out that if 12% of a natural region is receiving protection, this does not necessarily mean that all the region's important features are adequately represented. The data do not locate protected areas within a region or show their size and what features they represent. Such factors must be considered when evaluating the completeness of protected areas systems. The analyses on Figures 7.4, 7.5, 7.7, and 7.8 do not illustrate all areas that need immediate attention. Some important habitat types that are generally underrepresented across Canada include old-growth forests, wetlands, and urban natural areas.

Old-growth forests

At the current rate of logging, it is estimated that there will be no substantial ancient forest left on the British Columbia coast by the year 2008 (Young 1988; Daniel 1989). Currently, 1 856 km^2 of original forest are protected within ecological reserves, provincial parks, and the national parks in British Columbia — in all, about 2.6% of the original old-growth forests (Roemer *et al.* 1988). Pacific Rim National Park Reserve and South Moresby/Gwaii Haanas National Park Reserve are the only national parks protecting virgin coastal rain forest in Canada. Most of the old growth bordering Pacific Rim is destined for clearcutting, which will reduce the park stands to narrow ribbons of forest, once again raising the size issue and potential problems of biogeographic isolation. Carmanah Creek, the site of Canada's tallest trees, lies just beyond the boundaries of Pacific Rim. Part of this area is currently in the process of being set aside as a provincial park.

About 85% of British Columbia is designated as provincial forests. Ecosystem management in this area is the responsibility of the provincial Ministry of Forests. The survival of the rain forests depends upon the development of forestry policies that recognize that the ecological, spiritual, and recreational values of intact rain forest ecosystems can outweigh their short-term value as timber. The Ministry of Forests has recently introduced a new policy that recognizes wilderness areas in forest management plans. Such areas can be designated by orders-in-council. As part of British Columbia's old-growth forest strategy, a working group has been created to identify, and recommend protection of, critical sites within a network of protected areas.

Although the loss of old-growth forests is most dramatic in the coastal rain forests, virgin forests are threatened by logging throughout Canada (Thompson 1987). There is little original forest remaining in the Atlantic provinces, and what remains is disappearing rapidly. Of seven virgin red spruce forests selected as International Biological Programme sites in 1974, only one remained in 1989. Five were cut, and one was lost to spruce budworm infestation (R. Ogilvy, Nova Scotia Museum, personal communication). Only tiny remnants of virgin maple–beech forest characteristic of the St. Lawrence valley and the Great Lakes drainage basin remain.

Wetlands

Wetlands cover 14% of Canada (National Wetlands Working Group 1988). They act as natural water purification and flood control systems and provide important habitats for wildlife and fish, refuges for rare species of plants and animals, and important recreational resources (see Chapter 26).

Major achievements in wetland conservation have occurred in recent years across Canada. The North American Waterfowl Management Plan, signed in 1986 by Canada and the United States, calls for the preservation of 15 000 km^2 of wetlands in the Prairies and the Great Lakes basin by the year 2000. Most provinces have inventoried and classified their remaining wetlands, and some have formulated policies to protect the most valuable examples. The proposed Federal Policy on Wetland Conservation promotes wetland conservation on federal and provincial lands using a number of strategies, including the development of a system of protected wetlands of national significance.

Urban natural areas

There is much work yet to be done at the regional and municipal levels in establishing programs for the protection of significant natural areas in urban and rural settings. The concept of greenline parks (linear wild lands and green spaces), corridors, and systems of small natural areas that function cohesively to provide for the needs of wildlife and humans should be explored in Canada. The Ottawa greenbelt is an example of such a system. Similarly, a green waterfront trail has been proposed for a portion of Lake Ontario connecting Burlington and Newcastle. (See Chapters 13 and 26 for more information on urban green space.)

NEW APPROACHES FOR PROTECTING AREAS

As senior levels of government cannot hope to acquire every area and site needing protection, new means must be found to protect natural and cultural areas in Canada.

Ontario's Areas of Natural and Scientific Interest program was the first initiative in Canada to involve private landowners in identifying and protecting natural areas. Areas of Natural and Scientific Interest serve many of the same purposes as ecological reserves, although they are merely designated and have no guarantee of legal protection. More than 564 areas have been identified, 80% of these on private land. Through landowner contact programs and a tax rebate program, private protection of these sites is encouraged.

The Ontario Conservation Land Tax Reduction Program provides financial incentives to landowners of Provincially Significant Wetlands, Areas of Natural and Scientific Interest, and Niagara Escarpment Natural Areas to commit themselves to long-term stewardship. The rebate can be up to 100% of taxes. As of 1989, 3 500 landowners holding 440 km^2 of land had been approved as participants. Other financial incentives are offered through conservation easements, leases, and management agreements.

Similar landowner agreement programs have been initiated in the Prairies. Through these programs, landowners voluntarily agree to protect wildlife habitat. Signs, awards, leases, and other incentives acknowledge their participation. Under the Nova Scotia *Special Places Protection Act*, private lands can be designated as nature reserves with the permission of the owner.

The acquisition of properties by private nongovernment groups is a means of protecting land that is gaining momentum in Canada. The Nature Conservancy of Canada, since its inception over 25 years ago, has protected more than 300 km^2 of natural areas across Canada (Nature Conservancy of Canada 1989). The British Columbia Nature Trust, the Manitoba Habitat Trust, and the Island Nature Trust of Prince Edward Island have also acquired significant private holdings and offer an important alternative to government-acquired protected areas.

There is a nature trust in every province except Newfoundland and Nova Scotia. Future land protection in settled Canada will rely increasingly on private landowners and on growing cooperation between government and the private sector. Government and nongovernment organizations will have to promote stewardship programs and to provide incentives to private landowners and industrialists for the conservation of natural landscapes.

Similar approaches could be initiated with industrial users of Crown lands in less settled parts of Canada, and also as part of native land claims settlements. The pressures to log, mine, or flood large areas of wilderness are increasing yearly. Traditional means of acquiring land are costly and slow. Although the new approaches may not provide the same secure, long-term protection as legislated ecological reserves, they are an important contribution to Canada's protected areas mosaic.

CONCLUSION

Canada is committed to implementing the concept of sustainable development as presented in the Brundtland Report. Sustainable development requires, among other things, the establishment of protected areas representing all of Canada's landscapes and species. Also, to ensure that these areas continue to protect representative species and ecosystems, the integrity of protected areas must be a priority management objective of all levels of government.

A review of the amount of protected space in Canada reveals that, if only strictly protected areas are included, about one-quarter of the Green Plan's target of 12% has been attained. If all conservation lands (IUCN categories I–V) are included, slightly over half of the 12% target has been achieved. Much work remains to be done, and opportunities to do so are diminishing as more and more lands are committed to forestry, agricultural, mining, hydroelectric, and urban developments.

Although many jurisdictions have begun to identify a broad range of threats to protected areas, most simply do not possess the information or resources to adequately assess the integrity of Canada's protected area networks. The priorities of sustainable development, and the growing threats to protected areas, demand that we treat protected area programs as a priority for science and ecosystem survival, as well as for recreation.

Sustainable development implies that economic progress must be compatible with the long-term maintenance of natural ecosystems and life-support processes. A strategy to implement sustainable development requires not only the careful management of those lands and resources that we exploit to support our economy, but also the protection from development of representative natural and cultural areas.

The 1990s are widely regarded as the turnaround decade for environmental protection. Canada is in the fortunate position, relative to other countries, of still having the option to protect the full diversity of its heritage resources. It is an option, and a global responsibility, that must not be forfeited.

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HIGHLIGHTS

Canada's fisheries provide an important part of the nation's food supply, employ directly and indirectly over 100 000 persons, and generated $2.6 billion in 1988. The Atlantic fisheries are the largest, accounting for about 75% of Canada's commercial catch. Groundfish (mainly cod, pollock, and several species of flatfish and redfish) represent the biggest share of the total. In the 1980s, overharvesting caused severe declines in some important stocks of groundfish in the Scotia–Fundy region and on the Grand Banks.

■

On the Pacific coast, stocks of salmon — the most valuable catch in British Columbia — are almost as high as they have ever been, except for some individual stocks depleted by overfishing and degraded habitat near mines and mills. Some shellfish areas near pulp mills have been closed to fishing because levels of dioxins in crabs, prawns, shrimps, and oysters exceed the tolerance level for human consumption.

■

On the Arctic coast, no fisheries have been lost to overfishing or habitat destruction. Some fishing closures have resulted from local depletion of arctic charr populations. Populations of bowhead whales, beluga, and walrus have not yet fully recovered from past overexploitation.

■

Throughout Canada, freshwater fish stocks are in good condition. However, stocks in populated areas are declining due to overfishing. Managers are experimenting with new approaches to controlling the recreational fishery (which on fresh waters is double the size of the commercial fishery). Acid rain is responsible for the destruction of habitat and loss of fish in thousands of lakes in eastern Canada, and a number of former salmon streams on the east coast are acidified. Pollution in the Great Lakes–St. Lawrence River system has caused the disappearance of some formerly fished species and the decline of others.

■

Fisheries managers need more accurate statistics on fish harvested and improved knowledge of fish biology and marine ecology to enable them to steer the recreational and commercial fishing industries, and subsistence fishing, between the shoals of collapse of fish stocks, overcapitalization, unregulated foreign competition, toxic contamination, acidified lakes, and loss of spawning habitat.

■

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> **Few things on the planet are more fascinating than the biological problems of fisheries management. True, modern technology takes us under the water now, but we are still not at ease there, it is not our world nor likely to become so, and there is still the vastness of the oceans, of the great freshwater lakes, of even the smaller lakes. Water still hides much.**
>
> **— Roderick Haig-Brown (1980)**

INTRODUCTION

When John Cabot reached the shores of Newfoundland in 1497 he found the sea "swarming with fish, which can be taken not only with net, but in baskets let down with a stone." This illustration of the former abundance of "fish" (as cod are still referred to by contemporary Newfoundlanders) is in contrast with today's shortage of cod off Canada's east coast.

In 1990, Canada counted over 89 000 commercial fishers, 38 166 fishing vessels, and 1 270 fish processing plants (Table 8.1). On the Atlantic coast alone, about 1 000 communities are wholly or mostly dependent upon the fishery. Nationwide, fish and marine mammals are the basis for 130 000 jobs in commercial fishing and processing and 74 million days of recreational fishing per year. Canada is a major world exporter of fish, with a value of $2.6 billion, ranking 2nd in the world in value of exports and 16th in tonnage (Table 8.1). The exploitation of Canada's marine resources has been and will continue to be important in both national and international contexts.

The fish in Canada's salt and fresh waters represent a renewable resource that can be harvested indefinitely. However, the difficulty of doing so should not be underestimated. A major obstacle is that abundance of fish may vary greatly between fishing seasons. This can be a consequence of human-caused stresses, a multitude of poorly understood natural factors, such as weather and oceanographic conditions, which affect the survival rates of fish, or a combination of the two. Fisheries managers who aim for a sustainable fishery — i.e., one that provides social, economic, and environmental benefits indefinitely into the future — are in most instances only able to control the human-caused stresses, in particular the stress created by the fishery itself. In general, they have responsibilities on four fronts: management, protection, enforcement, and, increasingly, enhancement.

Management of fisheries is aimed at achievement of social and economic goals — employment in isolated coastal communities, for example — without damaging the biological capacity for sustained productivity. Protection focuses on maintaining the habitat requirements of particular species and the quality of aquatic environments in general. Enforcement ensures that the fishing industry adheres to regulations that limit annual levels of catch for different species and stocks. Enhancement aims to increase the harvest of desired species through measures that bolster natural productivity, improve natural habitat, and supplement natural production, as in the case of aquaculture. To the extent that management, protection, enforcement, and enhancement measures are successful, fish catches will be sustained or increased.

MANAGING CANADA'S FISHERIES

In Canada, the responsibility for fisheries is borne by the federal government, which has exclusive jurisdiction over sea, coastal, and inland fisheries. The discharge of federal responsibility rests largely with the Department of Fisheries and Oceans, acting under the authority of the *Fisheries Act*. The administration of fisheries varies in different parts of the country: for example, much of the management of inland fisheries is delegated to the provinces.

A sustainable Canadian fishery also depends on international cooperation. In the coastal zone, within 200 nautical miles[1] of shore, Canada has exclusive jurisdiction over fisheries; however, the country cannot, in isolation, manage transboundary stocks of fish that often move beyond Canada's 200-mile zone into international waters, where they may be caught by vessels from any nation. Similarly, transboundary stocks that cross the Canada–U.S. border in both marine and fresh waters, as well as Canada–Greenland stocks, are shared resources. Attempts to allocate responsibility for protection and allowable catches have led to a number of international agreements and understandings that depend on the cooperation of other nations.

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[1] The international community still uses nautical miles as a standard unit at sea, as opposed to the metric equivalent (200 nautical miles = 370 km).

Fisheries management extends to support of broad environmental goals. For example, Canada and the United States currently share responsibility for rehabilitation of the Great Lakes, the site of Canada's largest inland fishery, which have been substantially degraded as a consequence of eutrophication, pollution with toxic substances, overfishing, and the introduction of exotic species (see Chapter 18). More generally, international cooperation to counter global climatic change could help to prevent changes in distribution and abundance of fish stocks throughout Canada and off all three coasts.

Mechanisms for sustainable development

Management of the fishery

The concept of sustainable yield is a cornerstone of fisheries management. In essence, Canadian fisheries resources are managed to ensure a sustained economic and social value consistent with biological conservation. Thus, for each species harvested, estimates of yield are set on the basis of biological advice and estimated economic and social benefits.

Within that broad framework, management allocates the resource among various users, including recreational, native, and commercial fishers, using a variety of gear. Management plans for each species of fish are based on scientific advice and consultation with user groups. Fisheries managers routinely collect statistics on all landings.

Licensing, regulation, and enforcement are used to implement such plans. For virtually all Canadian commercial fisheries there is limited entry. Regulations concerning the dimensions of fishing vessels and the characteristics of fishing gear add a further level of control over fishing effort.

TABLE 8.1

Profile of Canadian fisheries, 1990[a]

Region	No. of registered fishers	No. of registered vessels	No. of registered plants	Nominal catches (t, 000s)	Value of landings ($, 000s)	Value of production ($, 000s)	Value of total imports ($, 000s)	Value of total exports ($, 000s)
Atlantic	61 356	29 198	918	1 213	906	2 092	174	1 708
Pacific	20 097	5 773	181	285	412	875	226	775
Inland	8 500	3 195	171	45	82	125	330	175
Canada	**89 953**	**38 166**	**1 270**	**1 543**	**1 400**	**3 092**	**730**	**2 658**

Note: Landings and production figures exclude aquaculture products.
Export figures include some transshipment of products from other regions.
Production figures are estimates.

[a] Preliminary estimates (data underestimate the final catch).

Source: Department of Fisheries and Oceans.

Control of effort is only one step towards controlling catch. To ensure that the yield conforms to the management plan, it is common practice to set a total allowable catch (TAC) for marine fish (capelin, mackerel, tuna, groundfish,[2] herring) and shellfish. The TAC is the allowable tonnage of a particular stock of a particular species that may be taken from a designated area during a specified fishing season. The TAC may be divided into allocations (quotas) for various user groups (e.g., traps, trawlers, gill-netters, offshore trawlers). There may also be an allocation of a perceived surplus to one or more foreign nations in the form of a quota to be taken under licence, for which an appropriate fee is charged. Each foreign vessel is required to have a Canadian observer on board to ensure compliance with terms of the licence. These observers also gather information and samples for scientific assessment of fish stocks.

Quotas for individual companies or vessels may further subdivide a TAC. As a refinement of catch control, these individual or "enterprise" quotas provide a measure of stability to the operations of the companies or vessels that have them by limiting the race for the fish and reducing costs in the industry.

Management of the Pacific salmon fishery requires particularly responsive controls over catch during the fishing season and illustrates the sometimes monumental task facing fisheries managers. Management involves close monitoring of catch and day-to-day adjustment of fishing times and areas to achieve both appropriate allocations of the stock and the permissible catch. Pacific salmon are allocated to the following categories: conservation, natives, commercial, and recreational. To determine the conservation allocation, the size of the incoming runs must be estimated: the objective is to permit the optimum number of salmon — of each stock of each of five species — to escape capture and return to their spawning streams. The commercial allowance is suballocated by gear sector: trawlers, seiners, gill-netters.

A problem in a number of fisheries worldwide is how to prevent harvesting beyond levels that will allow biological conservation. With every short-term upswing in natural abundance, optimism increases, leading to investments in better vessels and greater processing capabilities. The difficulties inherent in managing fisheries, especially those in decline, while attempting to maintain historic economic benefits are enormous. The so-called "boom and bust" fisheries cycle is at the core of current efforts of the Department of Fisheries and Oceans to monitor and control catches. The solutions will not be easily found; however, industry supports the department's efforts to maintain and rebuild fish stocks.

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[2] Commercially important fish species that live on the sea bottom.

Protection of habitat and productivity

Protection of the habitat for fish is a major element of sustainable development. Fish are barometers of ecological conditions. A decline in the numbers of fish and the accumulation of toxic substances in their flesh that renders them unfit for human consumption are clear signals of environmental degradation. Responsibility for protecting fisheries is embedded in the provisions of the federal *Fisheries Act,* but, constitutionally, freshwater resources are a provincial responsibility. In consequence, the close cooperation of federal and provincial agencies is critical to protection of aquatic environments.

It is not difficult to see harmful consequences of certain human activities: dams that block migrations of anadromous fish, irrigation diversions that alter stream flow, pollution by oxygen-consuming materials or toxic wastes such as mercury, dioxins, or heavy metals. Perhaps not as obvious is the fact that excess fertilizers, herbicides, and pesticides that leach from agricultural lands and sewage dumped into lakes and rivers cause major changes in aquatic flora and fauna and reduce production of favoured species.

Similarly, development projects in coastal areas — particularly in estuaries — may have substantial impacts on marine productivity. Water storage projects that modify the pattern of seasonal discharge may have significant effects on productivity and ice conditions in estuaries and other coastal waters (Drinkwater 1988). Proposals for such activities as dredging, harbour construction, transport of hazardous materials, causeway construction (McCracken 1979), and tidal power development require detailed review.

In reviewing these projects, a major element of federal government policy is the principle of "no net loss": the capacity for production of desired species should not be diminished. Projects that would reduce fish habitat should incorporate mitigation measures that compensate for the loss; where no such measures are feasible, the project may not proceed. Implementation of this policy has effectively halted much loss of fish habitat to other uses of water in lakes and streams, estuaries, and other coastal areas.

Prevention is the best protection against contamination of fish habitats. Elevated levels of toxic chemicals have been measured in fish downstream of effluent discharges from industries. Bioaccumulation of certain toxins can impair physiological, behavioural, and reproductive performance in fish. There may be similar effects on predators of fish should the toxic materials pass up the food chain. The long-term implications are not known because persistent toxins will continue to cycle in the natural ecosystems for years, if not decades. Close liaison between federal and provincial pollution control authorities has led to improved practices by industry and a reduction in pollution, but much more is needed. The legacy of less rigorous control in years gone by will command the attention of researchers and regulators for many years to come. Waters at the Canada–U.S. border are also subject to U.S. controls, both federal and state. Prevention of contamination is particularly difficult in the case of those toxic substances, including a variety of heavy metals, polycyclic aromatic hydrocarbons, and chlorinated organic compounds, that are sometimes transported over great distances in the atmosphere and subsequently deposited in Canadian waters.

Acid-forming substances arrive in the same manner. In recent years, acid precipitation has been identified as the cause of serious decline or elimination of fish populations from 150 000 lakes, one in every seven Canadian lakes east of the Manitoba–Ontario border. Some measures have been taken to reduce Canadian emissions of sulphur dioxide, the principal source of acid precipitation, but much remains to be done in both Canada and the United States to halt the loss of fish habitat (see Chapter 24). Some lakes and streams that were acidified are showing signs of natural rehabilitation; others will continue to be a challenge to research.

The introduction of exotic species, sometimes by accident and sometimes by design, has brought both benefits and problems to Canadian fisheries. The Great Lakes provide vivid examples of beneficial (Pacific salmon and rainbow trout) and problematic (sea lamprey) introductions. The recent accidental introduction of the zebra mussel will likely cause major economic and ecological problems. This small, inedible mollusc arrived in 1988 in the ballast water of a freighter and is now spreading rapidly, plugging industrial and municipal water intakes and threatening food supplies of indigenous fish populations and spawning habitats for fish (see Chapter 18).

The direct effects of fisheries on fish stocks are management issues. Their effects on aquatic environments are considered protection issues. Examples are the effects of ground trawls on the organisms living on the sea bottom and whether the overall productivity is enhanced by increased availability of food to predators and scavengers and the mixing of nutrients into the water. The disposal of the carcasses of unwanted species in the catch is a widespread practice whose impact has yet to be assessed. The possibility that fishing may influence the genetic composition of stocks has been much debated.

There are two other facets of protection that warrant mention. One is protection of the consumer from fish products that are contaminated with toxins — both those of natural origin and those that arise from human activities. The federal Department of Fisheries and Oceans, in cooperation with the provinces, has a number of programs for regulation of the handling and processing of fish, inspection and registration of fishing vessels and processing plants, and product inspection. Molluscan shellfish are monitored to detect paralytic shellfish toxins, domoic acid, and fecal coliforms. In certain areas there are routine analyses for contaminants such as dioxins, DDT, PCBs, heavy metals, mercury, and other potentially toxic substances.

The other protection issue is the projected global warming trend, which may be accompanied by substantial changes in patterns of ocean circulation and productivity, perhaps causing changes in the geographic distribution and relative abundance of various marine species. The overall impact on marine fisheries could be either positive or negative, depending on the conditions that develop. Climatic change could have a major impact on freshwater fisheries, especially in areas of low precipitation.

Enhancement and aquaculture

For over a century, Canadians have tried to enhance natural production of fish and shellfish using various techniques. In many instances the results were disappointing, but in recent decades greater knowledge has made enhancement practices more effective. At its simplest, enhancement may mean the fertilization of a lake or stream, construction of artificial spawning channels for trout or salmon, or preparation of artificial surfaces on which oysters, mussels, and scallops can deposit their spat (their young). More sophisticated measures include induced maturation and hatchery rearing of young, perhaps until a critical juvenile stage, such as smolting (young salmon leaving fresh water for the sea for the first time).

In Canada, both federal and provincial agencies carry out enhancement activities, which have been notably successful in recent years. For example, 15% of Pacific salmon production can now be traced to enhancement measures.

Many of the technologies of enhancement merge into those required for intensive aquaculture. Indeed, in international fisheries parlance, the practice of stocking young fish or shellfish into the natural environment is included under aquaculture. Both draw on a knowledge of nutrition, behaviour, induced maturation, genetics, and diseases of aquatic organisms. In brief, aquaculture is a sophisticated form of enhancement (or, put the other way, enhancement is a primitive form of aquaculture).

As aquaculture becomes more extensive, intensive, and diversified, there will be many new challenges. The competition with other interests will necessitate improved coastal zone planning and management.

REGIONAL ASSESSMENTS

Some species and stocks are quite stable, whereas others are highly variable. The status of a population reflects the natural and humanly induced influences on the abundance of the species and the effectiveness of management strategies.

It is difficult, at the best of times, to estimate the numbers of any particular species. The usual procedure is to take both statistics on catch and effort from commercial and recreational fisheries and data collected in research surveys into consideration. Because there are a large number of variables, many of which are not well understood, projections of permissible harvests are not as precise as managers and the industry would like. Nevertheless, over the years trends have become apparent, and knowledge of these trends may lead to new management practices.

The following sections provide, for several regions of Canada, an overall appraisal of the state of the fishery, followed by a description of the status of various major stocks.[3] In the case of the Atlantic and Pacific coasts, the regional profiles are accompanied by a series of graphic illustrations of trends in landings of fish and stock size of marine mammal populations. With good conservation practices controlling catch levels, such trends are a key indicator of the present health of the fishery.

The Atlantic fisheries

The combined Atlantic fisheries had a total production value in 1990 of $2.09 billion, accounting for 78% of Canada's total landings by weight and 67% by value (Table 8.1). The industry generates over 61 000 harvesting jobs. The fishing fleet includes 29 198 vessels of various types and sizes, and there are a total of 918 registered processing plants. The total catch for all species in 1990 was 1.2 million tonnes (Table 8.1). Groundfish represented the biggest share of the total landings (52%) in weight, led by the cod fishery with 381 819 t (Table 8.2). However, the invertebrate fishery (shrimp, lobster, crab, scallops, and clams) is the most valuable: it is worth $447.7 million for landings of 208 800 t.

Some fish stocks on the Atlantic coast have increased in recent years, and some have decreased (see Box 8.1). Catches from some of the major invertebrate stocks, like lobster, have soared to historic highs, and scallop stocks have also made a good recovery recently. Many of the pelagic stocks, including herring and capelin, are rebuilding from previous lows. The Canadian management strategy to limit foreign fishing and conserve stocks, which was implemented following the establishment of the 200-nautical-mile zone in 1977, has contributed to the recovery of previously depressed fish populations on the Atlantic coast. Groundfish populations have made great gains since 1977; some species, however, such as haddock off Nova Scotia, first increased but have since declined significantly, and northern cod off Newfoundland recently declined slightly, although TACs were reduced substantially when it was realized that previous exploitation rates had been higher than the target levels. The stock is now increasing as a result of improved recruitment. Recent changes in the management strategy are aimed at reducing domestic fishing capacity.

An international body called the Northwest Atlantic Fishery Organization (NAFO) exists to manage fishing in international waters of the Atlantic, but some member and nonmember countries have chosen to ignore its regulations. Foreign vessels continue to take immature fish in rich fishing areas just beyond Canada's fisheries waters, such

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[3] Data for 1989–90 are preliminary estimates, which generally underestimate the true final catch.

TABLE 8.2

Nominal catches and landed values by main species, 1990[a]

Species	Atlantic coast Q (t)	Atlantic coast V ($, 000s)	Pacific coast Q (t)	Pacific coast V ($, 000s)	Canada Q (t)	Canada V ($, 000s)
Total groundfish	634 061	375 782	130 991	73 009	765 052	448 791
Cod	381 819	239 398	5 502	2 902	387 321	242 300
Haddock	21 346	23 094	—	—	21 346	23 094
Redfish	80 326	22 006	23 380	14 343	103 706	36 349
Halibut	2 135	9 769	4 715	19 688	6 850	29 457
Flatfishes	71 515	37 184	5 926	4 364	77 441	41 548
Turbot	18 888	13 000	1 948	447	20 836	13 447
Pollock	36 819	19 381	545	143	37 364	19 524
Hake	13 087	6 981	79 890	10 982	92 977	17 963
Cusk	3 481	2 183	—	—	3 481	2 183
Catfish	1 516	397	—	—	1 516	397
Other	3 129	2 389	9 085	20 140	12 214	22 529
Total pelagic and other finfish	370 474	77 367	139 068	299 955	509 542	377 322
Herring	255 187	37 508	40 228	74 400	295 415	111 908
Mackerel	14 680	4 081	—	—	14 680	4 081
Tuna	466	6 715	272	837	738	7 552
Alewife	6 331	1 501	—	—	6 331	1 501
Eel	284	1 240	—	—	284	1 240
Salmon	515	2 286	95 271	223 470	95 786	225 756
Skate	98	6	132	23	230	29
Smelt	695	511	—	—	695	511
Capelin	89 787	17 546	—	—	89 787	17 546
Other	2 431	5 973	3 165	1 225	5 596	7 198
Total shellfish	208 838	447 705	15 068	34 898	223 906	482 603
Clams	18 914	14 089	6 227	14 405	25 141	28 494
Oyster	3 200	7 300	3 856	3 200	7 056	10 500
Scallop	80 029	96 264	68	315	80 097	96 579
Squid	3 851	1 003	47	51	3 898	1 054
Lobster	44 963	222 303	—	—	44 963	222 303
Shrimp	27 819	53 120	2 422	7 767	30 241	60 887
Crab	26 062	49 326	2 060	8 441	28 122	57 767
Other	4 000	4 300	388	719	4 388	5 019
Miscellaneous items	—	6 082	—	4 089	—	10 171
Total seafisheries	1 213 373	906 936	285 127	411 951	1 498 500	1 318 887
Inland fisheries					45 000	82 000
Grand total — Canada					1 543 500	1 400 887

[a] Preliminary estimates (data underestimate the final catch). Q = quantity; V = live-weight value.

Source: Department of Fisheries and Oceans.

as the Nose and Tail of the Grand Banks off Newfoundland. Canada continues to try to persuade these countries to respect the organization's advice.

Canada's own fishing fleets have substantially contributed to the current crisis in the fishery. In response to these problems, the Minister of Fisheries and Oceans established a Scotia–Fundy Groundfish Task Force (1989) and a Northern Cod Review Panel (1990). Off Nova Scotia, the groundfish fisheries have been plagued by domestic overfishing and misreporting, unsatisfactory levels of monitoring, surveillance, and enforcement, and a relentless increase in harvesting capacity, according to the report of the Scotia–Fundy Groundfish Task Force (1989). Particularly in the inshore fishery, this has led to fishing pressure exceeding target levels. Off Newfoundland, stocks of northern cod recently declined, due in part to the poor production of young fish.

The Scotia–Fundy Groundfish Task Force report made 28 recommendations. It called for conservation rules for gear, fishing times, and minimum sizes of fish, as well as increased enforcement and research. Members determined that the region's groundfish fleet had four times the fishing power necessary to take the permissible catch, so the task force recommended a major restructuring of the inshore groundfish fleet to reduce fishing pressure and allow stocks to recover. Currently quotas are dropping due to a decline in groundfish abundance. All the recommendations were designed to conserve stocks while minimizing socioeconomic impacts on fishers (Scotia–Fundy Groundfish Task Force 1989).

The Northern Cod Review Panel concluded that the stock was in decline and provided 29 recommendations. The most important urged a reduction in the catch of more than 50%, along with improved management practices and intensified research effort to better understand the status of the stock and the ecosystem that supports it (Northern Cod Review Panel 1990).

BOX 8.1

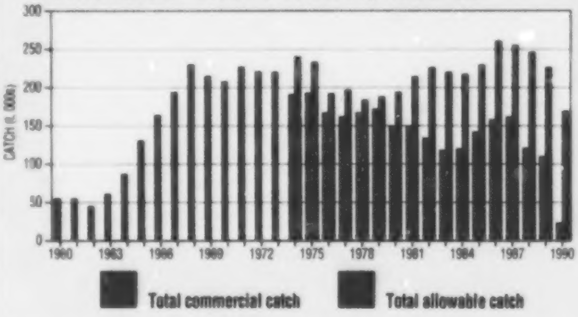
Trends in the Atlantic fisheries

Flatfish

There are 14 flatfish stocks in the Atlantic region, including American plaice, witch flounder, yellowtail flounder, Greenland halibut, and winter flounder. Landings peaked in the early 1970s and then declined. Landings, by weight, of American plaice, a major flatfish stock on the Grand Banks, are close to the lowest level recorded in 15 years. Recruitment (the number of young that reach breeding age) of American plaice is improving but is still well below long-term average levels. Overfishing of juveniles by foreign fisheries outside the 200-nautical-mile limit contributes significantly to the depressed state of this stock and of yellowtail flounder stock. If it continues, it will also reduce the size of the spawning population and subsequent recruitment.

FIGURE 8.B1

Commercial catch of flatfish, 1960–90[a]

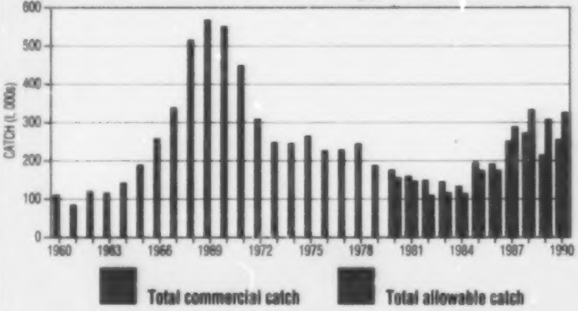


Herring

There are 10 Atlantic Canada herring stocks. Two are shared with the U.S.: one on Georges Bank, and one along the New Brunswick–Maine coast. In Canadian waters, herring are most abundant in the Bay of Fundy, but catches occur as far north as Labrador. In the 1960s, limits were placed on the annual catch. Herring stocks have fluctuated widely over the years due mainly to variations in recruitment levels. In general, stocks and landings have increased recently.

FIGURE 8.B2

Commercial catch of herring, 1960–90[a]

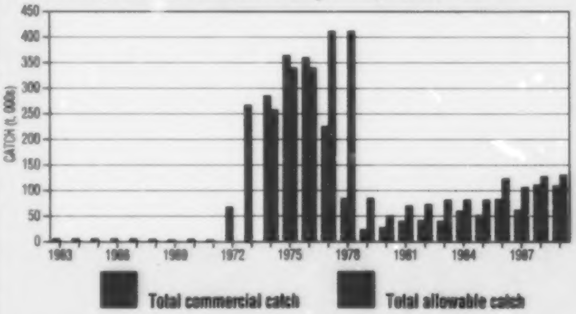


Capelin

Capelin in the northwest Atlantic are most abundant off the east coast of Newfoundland and on the Grand Banks, where they are a major food source for cod, whales, and seabirds, as well as the basis for a commercial fishery. Generally, capelin stocks spend most of their lives offshore, most stocks moving inshore to spawn on fine-gravelled beaches in June and July. Prior to the 1960s, they were fished inshore during spawning. Offshore (foreign) fisheries began in the 1970s, and stocks declined rapidly. The allowable catch was reduced severely in 1979 to allow the stocks to recover. With a subsequent increase in population size, catch levels have been allowed to increase.

FIGURE 8.B3

Commercial catch of capelin, 1963–89[a]



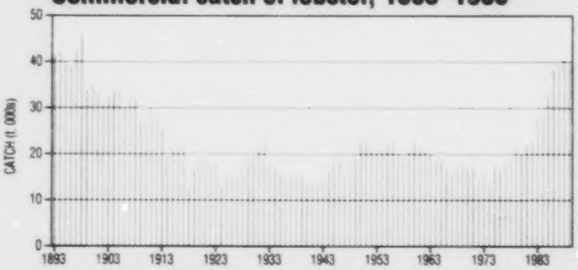
BOX 8.1 (CONT'D)

Lobster

Lobster is the basis of one of the most important commercial fisheries on the east coast. Canadian lobster fisheries occur from the Canada–U.S. border to southern Labrador. Lobster stocks have increased in recent years, and landings are now as high as they were in the late 1890s. Although some of the increase is due to increases in fishing effort (numbers of fishers and traps), there have also been improvements in the levels of recruitment for the various stocks. The reasons for the recent high survival of young lobster to minimum commercial size are not well understood. In the past, landings have been highly cyclical.

FIGURE 8.B4

Commercial catch of lobster, 1893–1989[a]

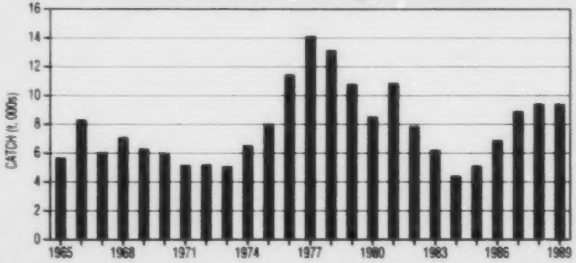


Scallop

There are two commercial species of scallop on the east coast, the abundant sea scallop and the less abundant Icelandic scallop. Sea scallops are harvested from the Canada–U.S. border to Labrador, but the highest concentrations are found in the Bay of Fundy and on Georges Bank. Scallop catches have increased in recent years largely as a result of good recruitment and settlement of the dispute with the United States on Georges Bank. Offshore biomass has been increasing since 1984, and landings have increased, although they are well below the peak in the late 1970s.

FIGURE 8.B5

Commercial catch of scallop, 1965–89[a]

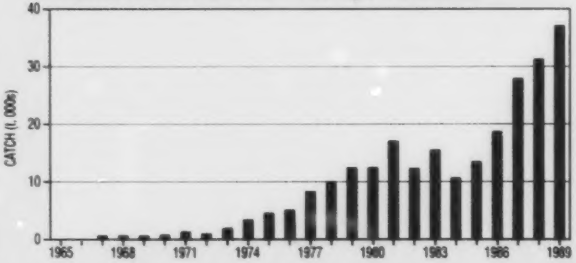


Shrimp

Shrimp fisheries in eastern Canada have shown rapid growth since the 1980s and are now ranked fourth in value among shellfish species, behind lobster, scallop, and crab. This growth, especially apparent in northern offshore regions, has been made possible by advances in technology, exploitation of new fishing areas, and maintenance of good market prices. The shrimp resources in eastern Canada are monitored through research surveys and sampling of the commercial catch. Based on the information obtained, estimates of yield and TACs are derived for each stock. This fishery is also controlled by limited entry, seasons, and mesh size regulations.

FIGURE 8.B6

Commercial catch of shrimp, 1965–89[a]

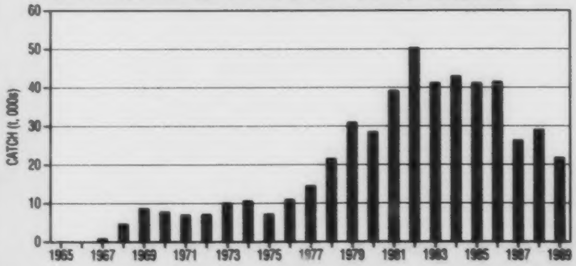


Snow crab

Snow crabs have been harvested since the mid-1960s off Newfoundland, throughout the Gulf of St. Lawrence, and off Cape Breton Island. This limited-entry fishery is also managed by trap limits, minimum snow crab size requirements, seasons (Newfoundland), and enterprise allocations (Gulf of St. Lawrence). Only adult male snow crabs, which are larger than females, are fished. Harvesting 50–60% of males annually does not appear to reduce the reproductive rate of the population, as almost 100% of the females carry eggs. Declines in recruitment resulted in a 50% drop in landings in the Gulf of St. Lawrence between 1986 and 1987, but there are signs that recruitment is improving. Other stocks are in good condition.

FIGURE 8.B7

Commercial catch of snow crab, 1965–89[a]



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[a] 1989–90 data are preliminary estimates.

Source: Department of Fisheries and Oceans.

Further, in May 1990, the Minister of Fisheries and Oceans responded to the Atlantic fisheries problems outlined in the recommendations of these two reports with a five-year, $584-million Atlantic Fisheries Adjustment Program, which provides financial assistance and incentives to help fishers and processing plants to adjust to reduced quotas. It also involves conservation measures, such as new minimum fish sizes, minimum mesh sizes for nets and traps, and other restrictions on gear to minimize the catch of small fish.

Groundfish

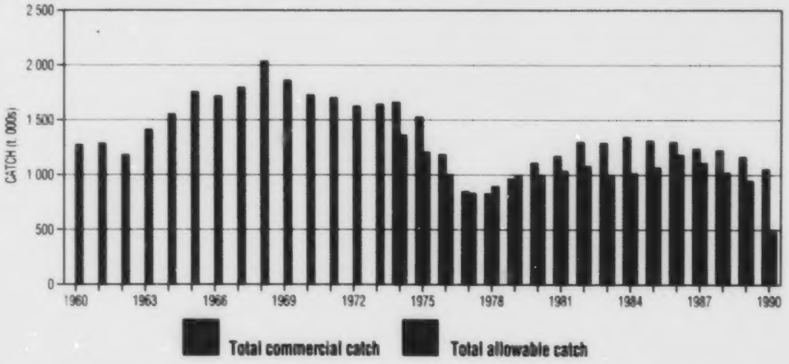
There are over 40 identified groundfish stocks on the Atlantic coast. The major commercial species are cod, haddock, pollock, several flatfish species, and redfish. Groundfish landings steadily increased during the 1950s and 1960s, mainly due to increased foreign fishing, but began to decrease in the early 1970s as overfishing depleted stocks. Limits on catches were introduced in the mid-1970s in an attempt to reverse the downward trend. Subsequently, with jurisdiction extended to 200 miles, Canada sought to conserve fish stocks and allow those that were depressed to recover. Although individual groundfish stocks have continued to fluctuate, the overall trend has been an increase between 1976 and 1989 (Fig. 8.1). However, since 1990, stocks of two of the most valuable groundfish species, cod and haddock, have become cause for concern.

Atlantic cod

In Newfoundland, "fish" means cod, which indicates the importance of this species to residents of "The Rock." Atlantic cod is a widespread species, with 11 stocks occurring between northern Labrador and the Canada–U.S. border on Georges Bank. Since 1976, annual quotas have been set for each stock. Landings have fluctuated, but the TAC has virtually doubled from 1978 to 1984 (Fig. 8.2).

FIGURE 8.1

Commercial catch of groundfish in the Atlantic fisheries, 1960–90[a]

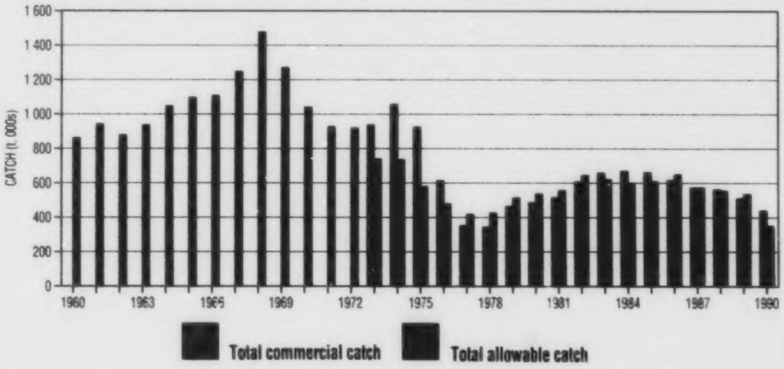


[a] 1989–90 data are preliminary estimates.

Source: Department of Fisheries and Oceans.

FIGURE 8.2

Commercial catch of cod in the Atlantic fisheries, 1960–90[a]



[a] 1989–90 data are preliminary estimates.

Source: Department of Fisheries and Oceans.

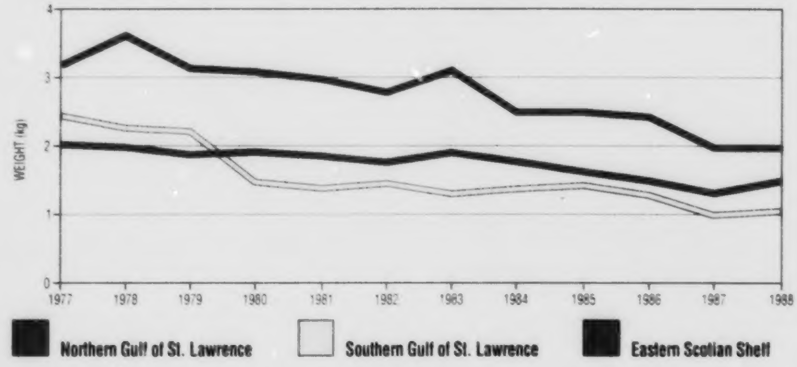
In a number of stocks, both the total population and the size of individual cod seem to be in decline. For some cod stocks, the weight of individual fish is now less than in the late 1970s. A seven-year-old cod in the southern Gulf of St. Lawrence weighed about 2.4 kg in 1977 but only about 1 kg in 1987 (Fig. 8.3). Perhaps as the stock became abundant in the late 1970s, there was more competition for food, thus slower growth. The decline appears to have stopped, and, in some stocks, the trend has now reversed.

Haddock

The size of haddock stocks is at an all-time low, prompting concern in the fishing industry and a concerted effort on the part of fisheries scientists to understand the biological and environmental factors — of which there are many in the rigorous North Atlantic — that influence the haddock's survival. It appears that successful survival from spawning is the exception rather than the rule (Marine Research Associates 1980), and there have been no encouraging signs recently, as recruitment

FIGURE 8.3

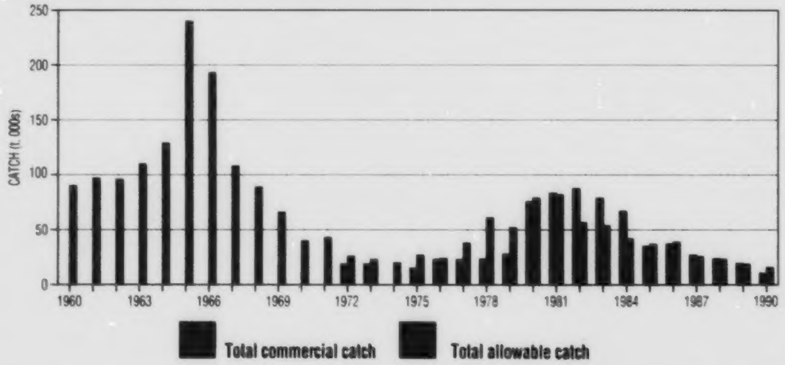
Trends in weight of seven-year-old cod, 1977–88



Source: Department of Fisheries and Oceans.

FIGURE 8.4

Commercial catch of haddock, 1960–90[a]



[a] 1989–90 data are preliminary estimates.

Source: Department of Fisheries and Oceans.

levels have continued to drop since the early 1980s, and landings have remained low (Fig. 8.4).

There are two major haddock stocks off Nova Scotia and one straddling the Canada–U.S. border on Georges Bank (Fig. 8.5). Stocks on the Scotian Shelf have been harvested very heavily, with over 50% exploitation rates annually. The scarcity of mature fish (over 0.43 m) has led to excessive fishing pressure on juveniles. Overcapacity in the Canadian industry, causing overharvesting, has been a major contributing factor, and scientists concluded that the high exploitation rates, if continued, may result in stock collapse (Scotia–Fundy Groundfish Task Force 1989).

Two major populations of haddock in Newfoundland waters declined in the 1960s. The Grand Banks and St. Pierre Bank stocks have not recovered.

Atlantic salmon, king of fish

"The Salmon is accounted the King of freshwater fish, and is ever bred in Rivers relating to the Sea," wrote no less an authority than Izaak Walton in *The compleat angler* (Walton and Cotton 1982). The Atlantic salmon is highly esteemed both as game and as food. During their spawning migrations, they ascend rivers and streams in New Brunswick, Newfoundland and Labrador, Quebec, Nova Scotia, and Prince Edward Island. In many areas, salmon runs have declined. Feeding areas at sea include all of the northwest Atlantic from the southern Grand Banks to the coast of Greenland along Davis Strait (Fig. 8.6).

A significant amount of the Atlantic salmon's freshwater habitat has been degraded or destroyed by dam construction, watercourse alterations, acidic deposition, mining, pulp and paper production, agriculture, and other sources of chemical pollution. Watt (1989) estimated that, based on the annual commercial catch record, the productive capacity of Atlantic salmon habitat in Canada had declined by 17% since 1870.

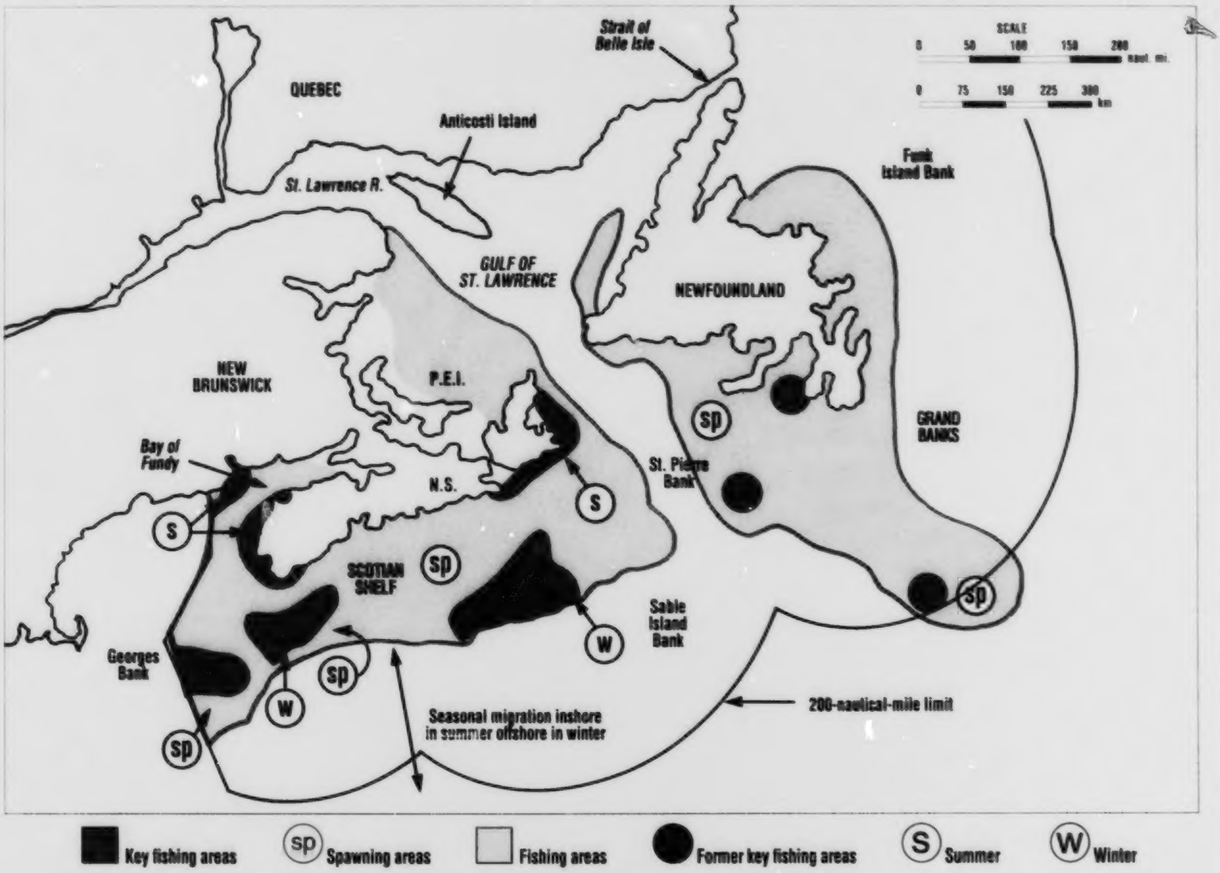
Commercial fishing of this species is currently permitted only along the north shore of the Gulf of St. Lawrence and in the Ungava region in Quebec, in Labrador, and in most of the coastal waters of Newfoundland. Restrictions, such as seasonal closures, gear restrictions, and TACs, apply to the commercial fishery. Figure 8.7 shows the variation in commercial landings for the salmon. A native food fishery accounted for about 2.5% of the catch by weight in 1988.

East coast recreational salmon anglers who fish only in fresh water took the remaining 17.5% of the total catch by weight in 1988. Restrictions that generally apply include seasonal closures, catch limits, and a required use of unweighted artificial flies. In many areas, anglers were restricted to grilse (fish weighing 1.5–3 kg that have spent one winter at sea before returning to their river).

Since 1980, the Department of Fisheries and Oceans has coordinated five salmonid enhancement demonstration projects in Newfoundland. Enhancement techniques include stream clearance, fishway construction, and stocking. On the Exploits River, for

FIGURE 8.5

Key areas for haddock in the Atlantic fisheries


Strait of Belle Isle
SCALE
0 50 100 150 200 naut. mi.
0 75 150 225 300 km
QUEBEC
Anticosti Island
St. Lawrence R.
Funk Island Bank
GULF OF ST. LAWRENCE
NEWFOUNDLAND
NEW BRUNSWICK
P.E.I.
GRAND BANKS
Bay of Fundy
St. Pierre Bank
N.S.
S
S
SCOTIAN SHELF
sp
sp
sp
Sable Island Bank
W
W
Georges Bank
sp
sp
Seasonal migration inshore in summer offshore in winter
200-nautical-mile limit
Key fishing areas
Spawning areas
Fishing areas
Former key fishing areas
Summer
Winter

Source: Scarrat (1982).

example, salmon production has increased significantly.

There are also a number of enhancement projects in the Gulf and Scotia–Fundy regions. For example, the distribution of artificially reared fish from salmonid enhancement centres has produced excellent results in several areas, such as the Margaree River, where early-run stocks[4] have recovered from near-extinction. Another project involves experiments in seminatural rearing, which have proven to be highly successful; returns to the Morell River of P.E.I. have been as high as 13%, greatly exceeding those from traditional rearing projects.

Marine mammals

Six species of seals belonging to the family Phocidae or "true seals" occur in large numbers in Canadian Atlantic coastal waters: harbour, grey, harp, hooded, ringed, and bearded seals. Populations of most of these species are believed to be increasing.

The harp seal is the basis of the commercial seal hunt in the Gulf of St. Lawrence and off northeastern Newfoundland; it has been substantially reduced in recent years. The Royal Commission on Seals and Sealing estimated that the harp seal population was approximately 2 million in 1985 and increasing by 5% each year. Extrapolation suggests a 1991 population of approximately 2.5 million. Analysis of a photographic survey of pup production carried out in 1990 will provide more recent data on the size of the stock. Research on the effects of seal predation on commercially important fish stocks is also under way.

Many species of whales, such as blue, fin, humpback, sei, sperm, minke, beluga (white), and pilot whales, are

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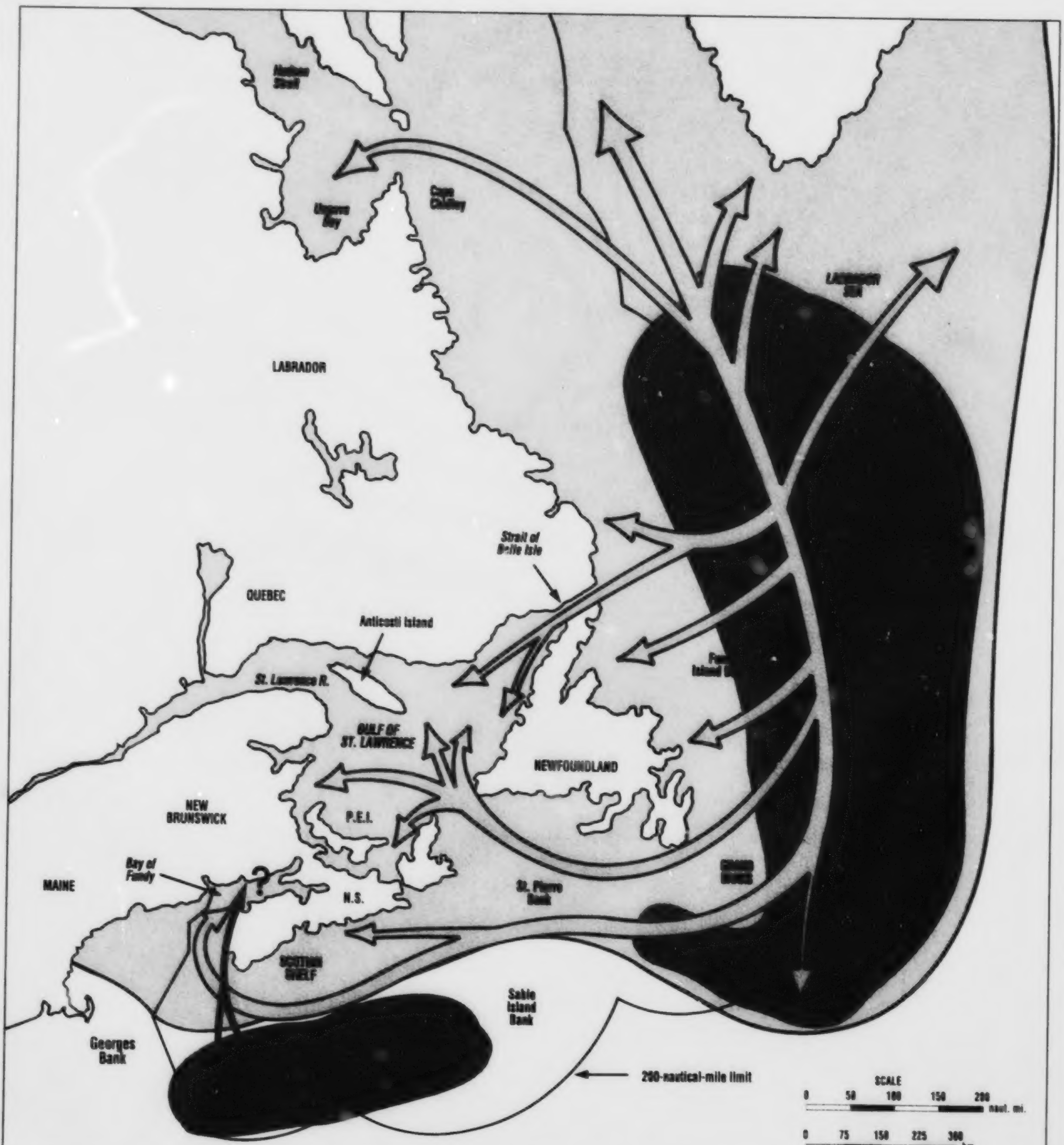
[4] Stocks that ascend to their spawning grounds early in the breeding season.

FIGURE 8.6

Migration routes of the Atlantic salmon


Hudson Strait
Ungava Bay
Cape Chidley
LABRADOR
Labrador Sea
Strait of Belle Isle
QUEBEC
Anticosti Island
St. Lawrence R.
GULF OF ST. LAWRENCE
Fu
Island B
NEWFOUNDLAND
NEW BRUNSWICK
P.E.I.
MAINE
Bay of Fundy
?
N.S.
St. Pierre Bank
Grand Banks
Scotian Shelf
Sable Island Bank
Georges Bank
200-nautical-mile limit
SCALE
0
50
100
150
200
naut. mi.
0
75
150
225
300
km
Winter distribution
Spring and summer distribution
Generalized migration routes
Possible Bay of Fundy migration

Source: Scarrat (1982).

found in Canadian Atlantic waters, including the Gulf of St. Lawrence. Some were subject to commercial whaling prior to 1973, and the current size of most of these populations is not well known. Some marine mammals are caught incidentally in gill nets and other gear. Recently, a recovery team was formed to investigate threats to the harbour porpoise population in the Bay of Fundy resulting from such catches.

The St. Lawrence population of the beluga is designated endangered by the Committee on the Status of Endangered Wildlife in Canada. Estimated at 5 000 in the late 19th century, the population has declined to approximately 500 (Sergeant 1986). Recent photographic surveys confirm this population estimate. Hunting was a significant threat to the St. Lawrence belugas earlier in this century. There is no sign of appreciable recovery since the ban on hunting was introduced in 1979 (Masse *et al.* 1986). Among the factors that may be responsible for this decline are loss of critical habitat, bioaccumulation of toxic chemicals, and disturbance by vessel traffic (see Chapter 19).

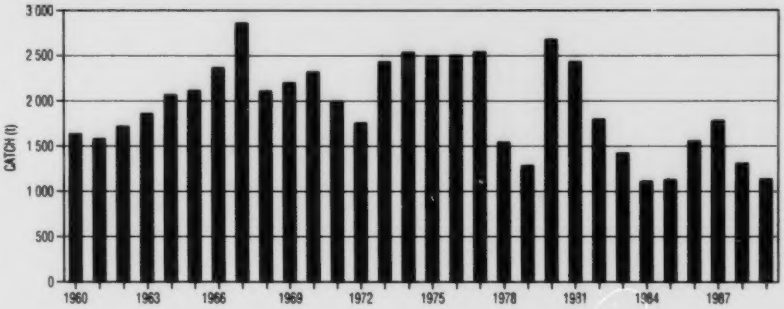
Various chlorinated organic compounds have been found in the blubber and organs of dead St. Lawrence belugas (Masse *et al.* 1986; Beland 1988). The levels of PCBs are comparable to those found in some populations of marine mammals that experienced reproductive dysfunction and population declines (Wagemann and Muir 1984) but are less than in other populations where no effects have been reported by the Canadian Atlantic Fisheries Scientific Advisory Committee.

The Pacific fisheries

Historically, the pattern of native settlement on Canada's west coast was associated largely with the accessibility of fish. Today, commercial fishing is the fourth largest primary industry in British Columbia, after forestry, mining, and agriculture. Fish harvesting accounts for about 4% of primary production in B.C., and fish processing accounts for nearly 3% of manufacturing activity. In 1990, almost 20 000 commercial fishers were registered in B.C. The commercial fishing fleet counted 5773 vessels, and fish were processed in 181 plants.

FIGURE 8.7

Total commercial catches of Atlantic salmon, 1960–89[a]

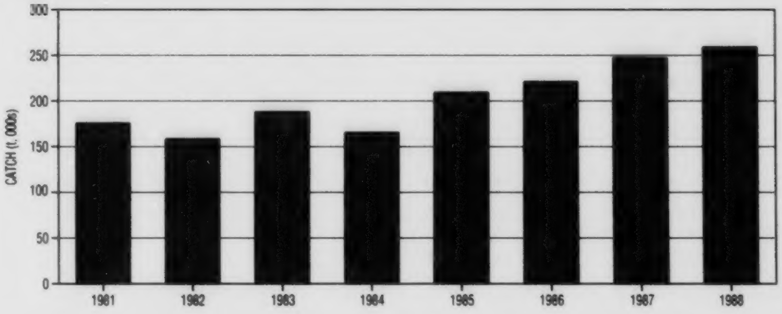


[a] 1989 data are preliminary estimates.

Source: Department of Fisheries and Oceans.

FIGURE 8.8

B.C. commercial fish catches, 1981–88



Source: Department of Fisheries and Oceans.

In 1990, fish landings generated about $412 million in landed value to fishers and $875 million after processing (Table 8.1). Salmon was the most important catch, accounting for 54% of the total value (Table 8.2). Herring ranked second, making up less than one-fifth of the value, followed by groundfish and shellfish.

British Columbia commercial fish landings have increased significantly since 1984 (Fig. 8.8). Record high catches of about 250 000 t were taken in both 1987 and 1988, mostly owing to a significant increase in salmon landings. Box 8.2 shows some trends in the Pacific fisheries.

Major influences on the Pacific fisheries

Fishing pressures

Despite these statistics, the commercial fishery on the Pacific coast faces challenges, foremost among them an enduring problem of overcapacity. With nearly 6 000 vessels and over 20 000 licensed fishers, the commercial fleet is overcapitalized. Commercial fishers see an increased quota and boat buy-backs as the answers to the industry's difficulties.

BOX 8.2

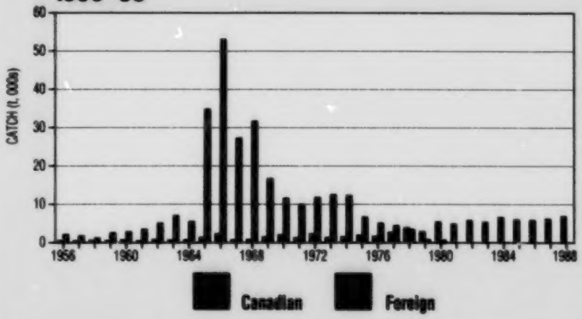
Trends in the Pacific fisheries

Pacific ocean perch

The populations of Pacific ocean perch have not recovered from overfishing by foreign vessels in the 1960s and 1970s. Increased recreational fishing for rockfish in the Strait of Georgia has contributed to a continued decline in the stock.

FIGURE 8.B8

Commercial catch of Pacific ocean perch, 1956–88

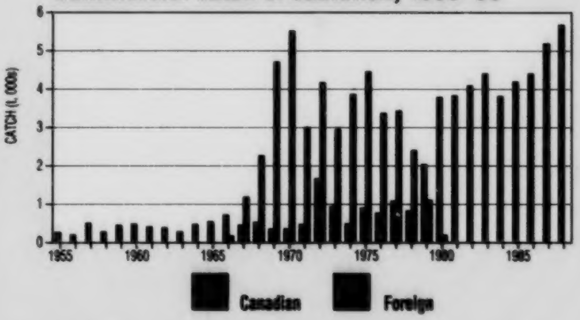


Sablefish

The Canadian catch of sablefish (black cod) grew from 2 000 t in 1979 to over 5 500 t in 1988 due to an increase in the number of domestic vessels that caught more fish and a strong year-class recruited in 1977. Because neither the combined foreign and domestic catches in the late 1960s nor the Canadian catches of comparable size in the late 1980s have depleted the stocks, the harvest forecast for this species is good.

FIGURE 8.B9

Commercial catch of sablefish, 1955–88

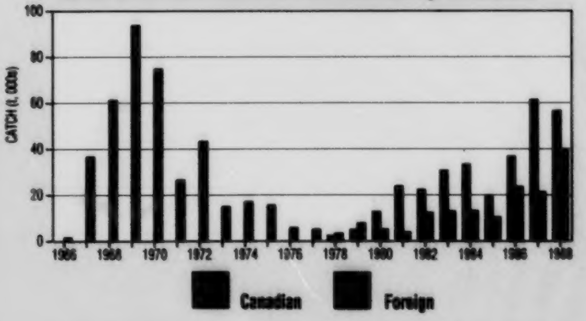


Pacific hake

A foreign–domestic joint venture fishery for Pacific hake was initiated in 1978 and in 1988 took 50 000 t. Both offshore and inshore stocks of hake are supported by intermittent, strong year-classes. Hake are at, or slightly above, average levels of abundance but are declining from previously high levels.

FIGURE 8.B10

Commercial catch of Pacific hake, 1966–88



Two major issues facing managers of the west coast salmon fishery are the allocation of catches to user groups and the prevention of by-catches of salmon from nontarget stocks. Inevitably, mixed species and mixed stocks are taken in the net fisheries; for example, net fisheries targeted on sockeye, pink, and chum also take chinook, coho, and steelhead — all species found together in ocean waters. Incidental catches, which may deplete smaller stocks, can be minimized in some instances by having people fish closer to the mouth of the river of origin of the target (so-called "terminal fisheries").

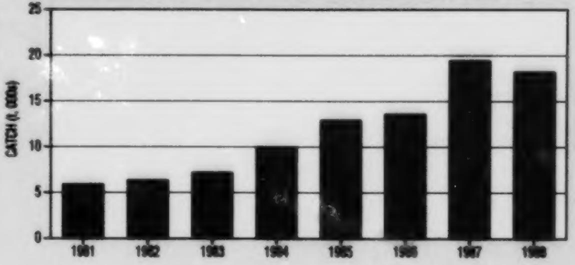
BOX 8.2 (CONT'D)

Shellfish

About 200 populations involving more than 25 species of shellfish are exploited by trapping, trawling, and diving. The most important species are geoduck clams, other intertidal clams, crabs, and shrimp. During the 1980s, the landings increased nearly threefold. Abalone may be overexploited, due in part to poaching, but recorded fluctuations in abundance are usually attributable to natural causes. Recruitment to the populations of shellfish is protected by setting the size limits for harvesting above the sizes at which they first spawn. A total closure was instituted in 1990 because of declining stocks. International markets are developing for a greater variety of shellfish species, suggesting that fishing pressure is likely to increase. For example, roughly 50% of the species now taken were not commercially harvested prior to 1982. Licences are now limited for the most heavily harvested species: for prawn this began in 1990, and for crabs and sea urchins in 1991.

FIGURE 8.B11

Commercial catch of shellfish, 1981–88

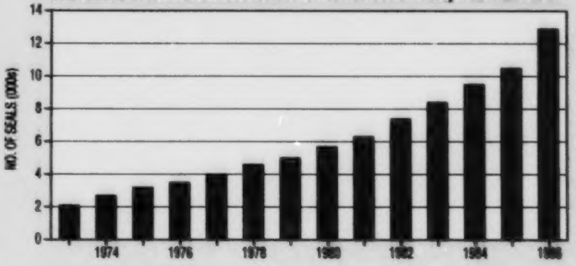


Harbour seals

Harbour seals are year-round residents in British Columbia. Until the late 1960s, they were killed for their pelts. By the late 1960s, the population was reduced to roughly 10 000 animals (Olesiuk *et al.* 1990). Given protective status since 1970, harbour seals have increased in number to an estimated 80 000, 16 000 of which live in the Strait of Georgia.

FIGURE 8.B12

Abundance of harbour seals in B.C., 1973–86

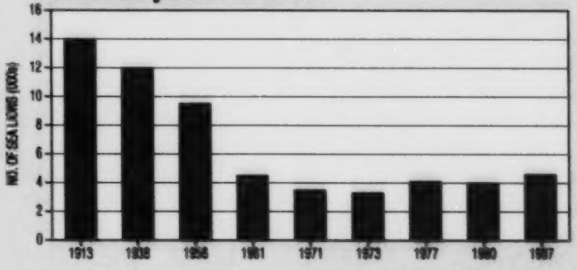


Steller's sea lions

Steller's sea lions gather each summer to breed on five rookeries along the B.C. coast. During the early 1900s, these rookeries contained 11 000–14 000 individuals. Population control programs reduced numbers to about 4 000 by the mid-1960s, and numbers have remained stable since that time. Control measures were instituted to protect the fish populations on which the sea lions preyed.

FIGURE 8.B13

Abundance of Steller's sea lions in B.C., selected years 1913–87



(Continued on next page)

The recreational fishery imposes a growing stress on salmon stocks. Coho and chinook are the primary salmon species caught in this fishery. An estimated 1.4 million salmon were caught by anglers in 1989, an increase of about 40% from 1983. Between 1983 and 1986, recreational fishing by residents increased by about 8%, and the number of visitors jumped 45%. In 1988, nearly 400 000 licensed recreational anglers spent about $400 million.

In B.C. and Yukon, about 85 000 native Canadians are eligible to fish for their traditional sustenance. Salmon are overwhelmingly important in this fishery, extensively taken from fresh water in the Fraser, Skeena, and Nass river systems. Statistics on native fishing activity are limited, due to complicated and often contentious issues of management. The estimated harvest increased from 350 000 fish in 1965 to about 1.3 million by 1990. Sockeye salmon account for about 80% of recent totals.

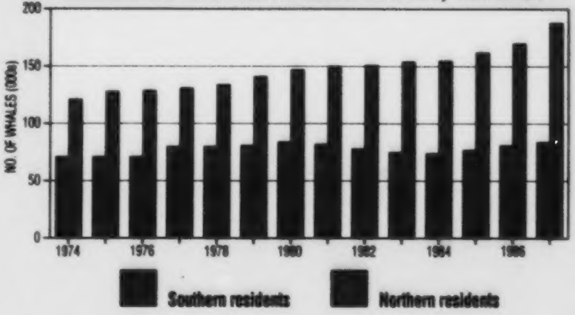
BOX 8.2 (CONT'D)

Killer whales

There are two distinct races of killer whales off British Columbia (Bigg *et al.* 1990). The "resident" race travels in groups of 10–20 individuals, feeding primarily on fish. The "transient" race normally travels in groups of 2–4 animals, eating seals and other marine mammals. The resident race has northern and southern components: to the north of the middle of Vancouver Island, there are 180 whales in 16 pods, and to the south, 80 whales in 3 pods (Olesiuk and Bigg 1990). Both communities have increased in number, at annual rates of 2.9 and 1.3%, respectively. The difference probably reflects the fact that juveniles were removed from the southern community from the mid-1960s to the early 1970s, for exhibits in zoos and aquariums.

FIGURE 8.B14

Abundance of killer whales in B.C., 1974–87



Source: Department of Fisheries and Oceans.

Management problems exist offshore as well. Canadian salmon are intercepted by U.S. salmon fisheries, and they are taken as an incidental catch in trawl fisheries and by high-seas drift-net fishing operations by Japan, Korea, and Taiwan. Concerns over interception of salmon of Canadian origin by the U.S. fisheries are dealt with under the Canada–U.S. Pacific Salmon Treaty. Impact of the high-seas drift-net fisheries, including interception of North American salmonid stocks, by-catch of marine mammals and birds, and ghost fishing of lost or discarded nets, is currently the subject of intense international negotiation (see Chapter 4). Canada has cosponsored a United Nations General Assembly resolution that calls for a ban on high-seas drift-net fishing by 1992, unless it can be shown that the environmentally damaging effects of a particular fishery can be controlled.

Habitat loss

Salmon require clean, well-oxygenated water with abundant food (e.g., zooplankton and small fish) for their survival and reproduction. Juveniles grow up in nearshore intertidal habitats, and some species spend considerable time in estuaries. Although, compared with fishing pressures, pollution exerts only a minor influence on salmon populations, localized habitat losses have nevertheless been identified. Examples are low dissolved oxygen in waters of Neroutsos and Alberni inlets and acute toxicity in intertidal habitats at Port Alice (Neroutsos Inlet), Gold River (Muchalat Inlet), and Woodfibre (Howe Sound). In 1989, it was estimated that 117 km^2 of benthic habitat had been directly smothered by either mine tailings, primarily in Rupert Inlet, or wood wastes in pulp mill effluents.

Further, widespread contamination of the marine ecosystem by low levels of organic chemicals poses an as yet undefined threat. In particular, sediments near pulp mill discharges have led to closures of fisheries for crabs, prawns, shrimps, and oysters, because dioxin levels exceeded the tolerance level for human consumption. These areas are now being monitored regularly. There had been no decline in dioxins in the affected species by late 1990 (the first closures occurred in late 1989) in spite of efforts by some mills to reduce releases of dioxins, and, indeed, some areas of closure have increased.

Recently, some losses of fish habitat have been offset by the federal government's new Fish Habitat Management Policy, which requires no net loss of productive fish areas. However, significant habitats were lost before the policy came into effect. Perhaps the greatest destruction was at the turn of the century in the Fraser River estuary near Vancouver, when an estimated 75% of the estuarial wetlands were drained for agriculture and became unable to support fish and other aquatic wildlife (see Chapter 16). The potential for habitat loss due to urbanization and industrialization continues to be a concern, especially when considering major estuaries such as those of the Fraser, Squamish, Nanaimo, and Cowichan rivers, which all support large salmon populations.

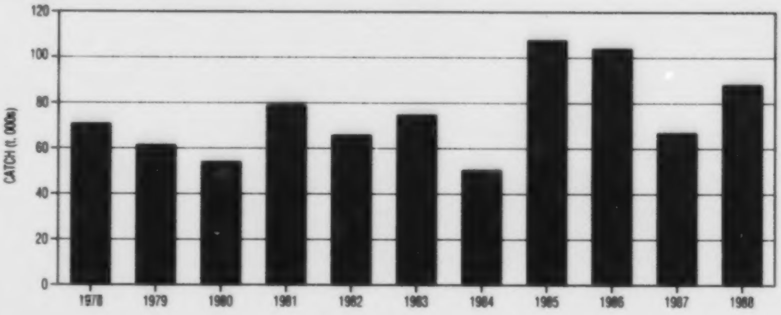
Dams

During the 1950s and in the early 1970s, various agencies proposed dams for hydroelectric power and flood control in the Fraser River system, but strong opposition eventually shifted construction to nonsalmon streams, such as the Peace and upper Columbia rivers. More recent candidates for hydroelectric dams include the Stikine River, a major salmon river, but increasing pressures for energy conservation have reduced the need for new sources of hydroelectricity.

Pressures also come from the private sector. In 1957, the Alcan Smelters and Chemical Ltd. built the Kenny Dam on the Nechako River, a tributary of the Fraser, and diverted water through the Coast Mountains by tunnel

FIGURE 8.9

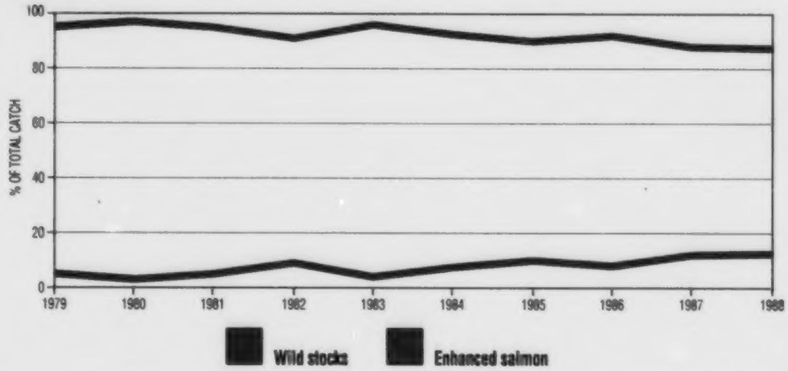
Commercial catches of B.C. salmon, 1978–88



Source: Department of Fisheries and Oceans.

FIGURE 8.10

Contribution of enhancement to the B.C. total catch of salmon, 1979–88



Source: Department of Fisheries and Oceans.

to its Kemano River powerhouse. In 1979–80, Alcan reduced the Nechako discharge to only one-third of that considered necessary to safeguard chinook salmon production. After court actions by both the federal government and the company, the two sides settled out of court in 1987. Alcan was given the right to use Nechako River water, provided the company monitors and protects salmon in the river, a compromise that some citizens continue to fight. More recently, court action has determined that the project will be subject to an environmental impact assessment.

Status of Pacific stocks

Salmon

Six hundred stocks of five species of salmon spawn in more than 1 800 streams in British Columbia. Ideally, each stock should be managed individually; in practice, only the largest, most economically important stocks are given close attention, and smaller or less productive populations are not directly managed.

Throughout the North Pacific, salmon catches were at historically high levels in the late 1980s. Canada's share of this nearly 750 000-t annual harvest has averaged about 11% (80 000 t) over the past five years (Fig. 8.9), ranking fourth behind the United States, Japan, and the U.S.S.R. Since the 1960s, protection and enhancement efforts have been a factor in increased catches. Approximately 4.7 billion hatchery-raised salmon were released into North Pacific waters in 1987; by 2000, the number is expected to rise to 6–7 billion. Salmon enhancement accounted for 10–15% of the total catch by Canada in the late 1980s (Fig. 8.10).

Catches of sockeye, pink, and chum salmon increased slowly in the 1980s. For sockeye, escapements (the number of fish that survive all fisheries and are estimated to be on the spawning grounds) are stable or increasing for stocks that are intensively managed or enhanced by stream improvements and lake fertilization. Although pinks are faring well in the Fraser River, other south coast stocks are in decline; central and northern coast stocks are stable or building slowly. Chum salmon escapement is highly variable and poorly known. Research is needed to ascertain whether the total runs of central and northern coast chums have diminished.

During the 1960s and early 1970s, commercial and recreational catches of coho and chinook salmon increased steadily, as hatchery-released fish soared to 40% of the total B.C. catch. Wild stocks of both species have declined off the southern B.C. coast since the 1950s, resulting in a 60% decline in spawning escapement and wild fish in the catch. Studies have shown that 75–80% of the population is frequently harvested per generation. Chinook tend to remain in coastal water and are caught throughout their life at sea. As a result, the rate of harvesting has exceeded 75%, which is greater than can be sustained. Reduced catches may also be due to diminished survival of hatchery-reared chinook. With a few exceptions, however, chinook stocks are rebuilding overall, due to management plans implemented through the Pacific Salmon Treaty between Canada and the United States.

Herring

In the 1950s and 1960s, herring were the subject of an intense fishery for oil and meal. With below-average recruitment in the mid-1960s, the fishery collapsed. After a closure in 1968 the populations recovered quickly (Fig. 8.11), and in 1972 a fishery for roe (eggs) was initiated.

The roe herring fishery in British Columbia requires special management to protect the spawning stocks from overharvesting. The fishery is short and intense, and stocks are exploited by a fleet with enormous fishing capacity: some fishing seasons have lasted less than an hour. Since 1982, the fisheries have been managed with a "firm harvest rate" policy. That is, every year, only 20% of the forecast biomass is allocated to the herring fishery; if biomass of a population is low, the fishery in the area may be closed to protect the spawning stock. In general, follow-up assessments of the spawning stock have proved the validity of the management actions. Herring fisheries in southern B.C. and the Queen Charlotte Islands were closed in 1986 and 1988, respectively, when stocks were low.

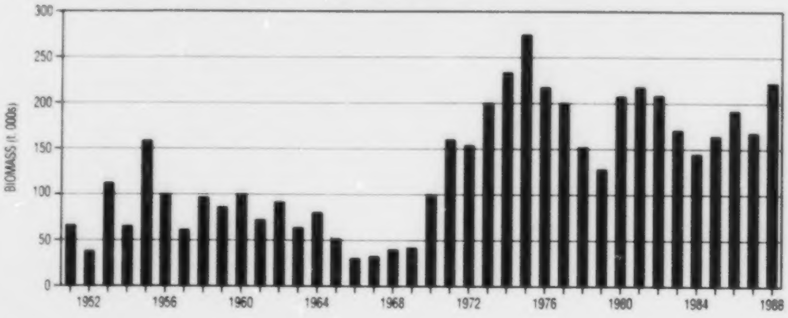
Groundfish

The groundfish fishery on the Pacific coast of Canada uses a variety of gear to take a diverse group of over 20 fish species in depths ranging from 100 to over 1 000 m. In order of economic importance, the principal species are halibut, sablefish, rockfish, Pacific hake, Pacific cod, and sole.

The state of groundfish stocks is probably best characterized by trends in the combined production of all species harvested. The groundfish fishery is managed as a year-round fishery with assigned quarterly TACs controlled by trip limits or selective closures. Overall, recent stock assessments seem to indicate that most groundfish populations are in satisfactory condition.

FIGURE 8.11

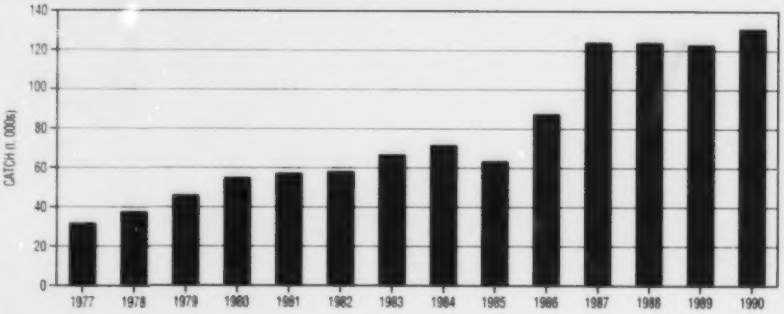
Spawning biomass of Pacific herring in B.C., 1951–88



Source: Department of Fisheries and Oceans.

FIGURE 8.12

Total catch of Pacific groundfish in B.C., 1977–90[a]



[a] 1989–90 data are preliminary estimates.

Source: Department of Fisheries and Oceans.

Although most Pacific groundfish stocks are at reasonable levels, the TACs are being spread among an increasing number of fishing vessels, necessitating shorter seasons or smaller trip limits. The increasing number of regulations is a source of contention with the industry, and the industry continues to pressure managers to raise harvest levels.

Since the introduction of the 200-mile offshore limit in 1977, the Canadian groundfish fleet has expanded fourfold. This is reflected in reported landings, which increased from about 30 000 t in 1977 to over 130 000 t by 1990 (Fig. 8.12). Over the same period, foreign fishing for all groundfish except hake was phased out. Foreign fishing for hake will be phased out in 1992.

In common with the east coast, a major problem in the groundfish fishery is that catching capacity of the commercial fleet far exceeds the sustainable yield of fish. The recreational fishery for certain species of groundfish (rockfish and lingcod) is expanding rapidly and putting additional pressure on these species. At the end of the 1980s, three groundfish populations were depressed as a result. Lingcod stocks were at historically low levels in the Strait of Georgia. The strait's rockfish stocks are also low, as are stocks of Pacific ocean perch.

Halibut

The halibut fishery is one of the oldest and most valuable on the Pacific coast. The fishery has a long history of regulation, beginning with the 1923 Canada–United States Convention for the Preservation of the Halibut Fisheries, an agreement to address severe depletion from overfishing. The stocks were rebuilt and supported a lucrative and sustained fishery until offshore trawling by foreign vessels seriously reduced recruitment. When the foreign fishery was curtailed, stocks recovered; during the early 1980s, the halibut catch increased 250%.

After 1986, however, halibut biomass declined. The 1990 TAC was 3 600 t, down from near-record highs of 5 700 t in 1988. The recent downturn can be traced to the increased by-catch of juvenile halibut by American trawlers in Alaska. The mortality of these juveniles has had a significant impact on the entire population from the Bering Sea south to Washington State waters. In July 1991, the International Pacific Halibut Commission and the Government of Canada successfully persuaded the United States to reduce the by-catch by 25% by 1993.

Arctic fisheries

Arctic fish and marine mammals have supported the Inuit for thousands of years, and emerging commercial fisheries will contribute to an increasingly diversified northern economy. Currently, the principal fishery is for arctic charr, once fished almost entirely for domestic purposes but now fished commercially (Bird and Rapport 1986).

The size, exploitation, and trends in the abundance and biomass of most arctic fish stocks cannot be accurately assessed because of inadequate fisheries statistics, particularly for the subsistence fishery. Statistics on the commercial and recreational catches are better, but improvement is needed (Crawford 1989).

Most arctic fish populations appear to be in generally good condition, except for a few arctic charr stocks. The effects of intense historic commercial whaling on the bowhead whale population and some stocks of beluga persist today. Fisheries for shrimp and groundfish in Davis and Hudson straits will bear close watching.

Future oil and gas development and the long-range transport of airborne pollutants have the potential to affect a broad spectrum of arctic marine life. Control of long-range transport of airborne pollutants will require international cooperation. Recent findings indicate that chlorinated organic compounds are entering the human population through the consumption of blubber from marine mammals.

Finfish

Most arctic charr stocks are stable, but the domestic harvest is uncontrolled, and many stocks near communities are heavily exploited. Rivers supporting overexploited stocks have been closed to allow recovery of charr populations (e.g., the Diana River near Rankin Inlet and the Big Fish River near Aklavik). A few remote stocks are harvested commercially, but many unexploited populations still exist.

There are important fisheries in the western Arctic for whitefish species: broad whitefish, lake whitefish, arctic cisco, least cisco, and inconnu. These species are taken within the Mackenzie delta channels and along the coast, primarily east of the delta. A survey of Mackenzie delta fisheries indicated that 81% of all fish caught went to domestic consumption, 62% of them being broad and lake whitefish.

Marine fish (135 species) from arctic waters are little used, and information on the distribution, life history, and population dynamics is limited. As a major food source for many species of fish, birds, and mammals, the arctic cod is probably the most important.

Minor local subsistence fisheries make limited use of Greenland cod, northern cod, polar cod, Atlantic cod, capelin, starry flounder, arctic flounder, Greenland shark, lumpfish, and various sculpins.

Recently, two species have been the targets of exploratory commercial fisheries — Pacific herring in the western Arctic and Greenland halibut in the eastern Arctic. Harvests of Greenland halibut have risen rapidly, from less than 2 t in 1986 to about 100 t in 1989.

Marine mammals

"The northern seas were (and are) rich enough to support a great sea mammal wealth," wrote Fred Bruemmer in *The Arctic* (Bruemmer 1982). That wealth has diminished, but bowhead whales, beluga, narwhal, walrus, and five species of seals still inhabit Canada's arctic waters. Except for bowhead whales, several stocks of each of these species support subsistence fisheries. Bowhead whales are classified as endangered by the Committee on the Status of Endangered Wildlife in Canada due to historic commercial whaling. Stocks in the eastern Arctic show few signs of recovery, even in the absence of hunting. The stock inhabiting the western Arctic is recovering well and supports a significant aboriginal hunt by the Inuit of Alaska. In 1991, the Inuvialuit of the Canadian western Arctic received a licence to harvest one bowhead whale, pursuant to their constitutional harvesting rights to keep alive this element of their culture.

In 1987, more than 4 000 residents of 34 arctic communities took a reported 662 beluga, 181 narwhal, 319 walrus, and probably more than 40 000 seals of all species. Prior to the collapse of the international fur markets in 1983, northern hunters harvested about 61 000 seals annually. Pelts are often discarded now, as there is no market for them. Other marine mammal products, such as narwhal and walrus ivory and whale bone, are used in the production of sculpture and other artwork. The wholesale value of these products is about $2 million per year for northern communities.

Bowhead populations across the western Arctic and beluga populations in parts of Hudson Bay, Ungava Bay, and southeast Baffin Island are reduced as a result of past whaling. Beluga stocks elsewhere are considered to be relatively unaffected by harvesting. Walrus are reduced in range and probably number, as are harbour seals. Other species of seals and narwhal show no evidence that harvest levels are unsustainable.

Ringed and harp seals make up 84 and 12%, respectively, of seals hunted in northern Canada. The bearded seal ranks third in catches at 4% and is essential to the resource-based Inuit culture. Hooded seals and harbour seals are relatively unimportant. None of these species appears to be threatened at current exploitation rates. Ringed seals are found in all arctic regions and are the most abundant and widely distributed seal in the Canadian North. An estimated 6–7 million ringed seals inhabit the Arctic Ocean.

Freshwater fisheries

Canada holds a good proportion of the world's fresh water, including seven of the world's largest lakes, which are home to some 180 species of fish. In many regions of the country, trout species are the most economically important, followed by walleye, yellow perch, rainbow smelt, whitefish, northern pike, and various bass species (Table 8.3).

Human-caused stresses on stocks of freshwater fish

Stocks of freshwater fish in areas of high human population density are in decline, mainly because of overfishing and habitat degradation. Declines are most evident in the southern parts of the western provinces, in the Great Lakes region, and in a few areas of Atlantic Canada. The Great Lakes, in particular, show the symptoms of a stressed ecosystem: increased abundance of short-lived exotic species, loss of the more desirable native species, and significant levels of persistent contaminants in aquatic organisms and sediments. The effects of acidic deposition are widespread but diminishing in eastern Canada, and, even in relatively remote areas, forestry, mining, and dam construction affect the health of aquatic life. Contamination of fish with mercury and a variety of organic pollutants not only is harmful to the fish but can, at high enough levels, render them unfit for frequent human consumption.

TABLE 8.3

Freshwater fisheries in Canada's major drainage basins

Drainage basin	Location	Species of importance	Type of fishery
Atlantic, excluding Great Lakes[a]	northern Ontario, Quebec, New Brunswick, Labrador	brook, brown, rainbow, and lake trouts; walleye, bass, northern pike, yellow perch, white perch, striped bass; smelt; introduced Pacific salmon and lake whitefish	recreational
		alewife, smelt	commercial
Pacific		rainbow, cutthroat, and lake trouts; Dolly Varden, kokanee, arctic grayling, mountain trout, whitefish	recreational and subsistence
Hudson Bay		lake whitefish, walleye, yellow perch, northern pike, sauger, mullet (suckers), arctic charr, mountain trout	subsistence
	western areas	whitefish, cutthroat trout	recreational
	southern areas	walleye, northern pike, yellow perch, rainbow trout	recreational
	northern and eastern areas	lake and brook trout, arctic grayling, lake sturgeon	recreational
Arctic		walleye, lake whitefish, northern pike, arctic grayling, lake trout, arctic charr	subsistence, recreational, and commercial
	Great Slave Lake	lake whitefish, lake trout, inconnu, walleye, northern pike	commercial

[a] See Chapter 18 for information on the Great Lakes fisheries.

Throughout the developed areas of Canada, recreational freshwater fishing is supplanting commercial fishing and is now more than twice as large, averaging more than 10 000 t per year. Ontario, Quebec, Alberta, British Columbia, Saskatchewan, and Manitoba, in descending order, have the largest provincial and territorial recreational fisheries (Beamish *et al.* 1987). Recreational fisheries contribute more than $4.4 billion to the economy each year. The extent of the fishery has led to some overfishing; this has been compounded by the uneven distribution of fishing pressure in terms of both geography and fish species. Stocks in remote lakes are generally little exploited, but, when access is improved by logging or mining roads, anglers soon follow. Fishery managers are promoting various strategies, such as reduced bag limits, catch and release fishing, barbless hooks, and size restrictions, in an effort to stem the growth in recreational fishing.

The commercial annual catch of freshwater fish in Canada averaged 50 800 t from 1955 to 1982 and totalled 45 000 t in 1990 (Table 8.1). It ranged from a low of 39 700 t in 1976 to a high of 62 000 t in 1962. More than 20 species are taken in commercial harvests. Walleye, yellow perch, lake whitefish, smelt, alewife, and northern pike are the most sought-after species.

Ontario, Manitoba, and Saskatchewan account for about 49, 33, and 10% of landings by weight, respectively. These are followed by the Northwest Territories, Alberta, New Brunswick, and Quebec, with lesser amounts. There have been no consistent trends in landings in Ontario and Saskatchewan. Catches declined in Manitoba during the late 1960s and 1970s, then rebounded in the 1980s. Commercial harvests have declined in Alberta, Quebec, Yukon, and the Northwest Territories (Beamish *et al.* 1987). The decline in the Northwest Territories has been due to declining effort, which, in turn, is the result of low prices and high costs and not stock depletion.

Subsistence fisheries, although locally very important to aboriginal peoples, generally are the smallest of the inland fisheries. However, in the Arctic, although definitive data are lacking, the subsistence fishery is probably almost as large as, or larger than, the commercial fishery.

Great Lakes fisheries: back from the brink

Despite three centuries of habitat degradation, overfishing, and introduction of exotic species, the Great Lakes still support one of the largest freshwater commercial fisheries in the world and account for over one-half of the total landed value of Canada's inland commercial fisheries.

The Great Lakes also provide the world's largest freshwater recreational fishery. The gross economic value of the Great Lakes has been estimated at $4 billion annually (Boulanger and Charbonneau 1989). The commercial fish catch in 1988 was 28 000 t, estimated to be worth $55 million. There were about 2 000 commercial freshwater fishers working on approximately 300 registered commercial fishing vessels, and the fishery provided 3 000 processing jobs in about 180 fish plants. Subsistence fisheries on the Great Lakes are few and small — less than 2% of the total commercial harvest of Ontario.

The Great Lakes fisheries for a number of species has declined over the long term. Commercial catches of lake trout, for example, remain low to nonexistent, in sharp contrast to those of the early 1900s. The blue walleye (also known as blue pike) was fished to extinction, and traditionally less valued species such as bullhead, yellow perch, American eel, white perch, lake whitefish, sunfish, and carp are today the largest part of the commercial catch in Lake Ontario. But there are some recent positive trends. Severe declines in lake whitefish in the early 1960s due to overfishing and lamprey predation have been reversed in the upper lakes, Huron and Superior.

The toll of species extinctions has been high in the lower Great Lakes. For example, over 10% of the estimated 75 species that were once found in Lake Ontario have disappeared (Christie 1973). Attempts to reintroduce species such as Atlantic salmon and lake trout have not been encouraging, but efforts continue.

Pollution is of particular concern in the Great Lakes–St. Lawrence River system. Contaminants have influenced the development of major fisheries in the last two decades through the closure of fisheries and erosion of public confidence. Mercury led to closure in western Lake Erie and Lake St. Clair in 1970. Though some fisheries reopened in 1973, others remain closed to commercial fishing, with reallocation of available fish to the recreational fishery. Mercury contamination also prompted temporary closure of fisheries in lakes Ontario and Superior. Contamination by the insecticide mirex has temporarily closed several Lake Ontario fisheries. PCB contamination now severely limits the harvest of carp from most parts of lakes Ontario and Michigan. Unsafe levels of PCBs were responsible for the closure of the commercial fishery for Pacific salmon in lakes Ontario, Erie, and Huron in 1976, and available fish have been reallocated to the recreational fishery.

Whether purposeful or accidental, introductions of new species into the Great Lakes have had both positive and negative effects. Stocking of Pacific salmon and rainbow and brown trout has generated significant recreational fisheries throughout the Great Lakes, accounting for over 5% of the current Ontario recreational catch, valued at over $351 million annually. At the same time, fishing pressure has been shifted away from the lake trout, a species currently targeted for rehabilitation.

Alewife and rainbow smelt today are a major portion of the diet of salmonids, both exotic and indigenous. However, these salmonids have eliminated or reduced the numbers of historically important forage species such as lake herring. The introduced common carp destroys marsh habitat, directly by uprooting plants in search of food (Powles *et al.* 1983) and indirectly by increasing turbidity (Whillans 1979).

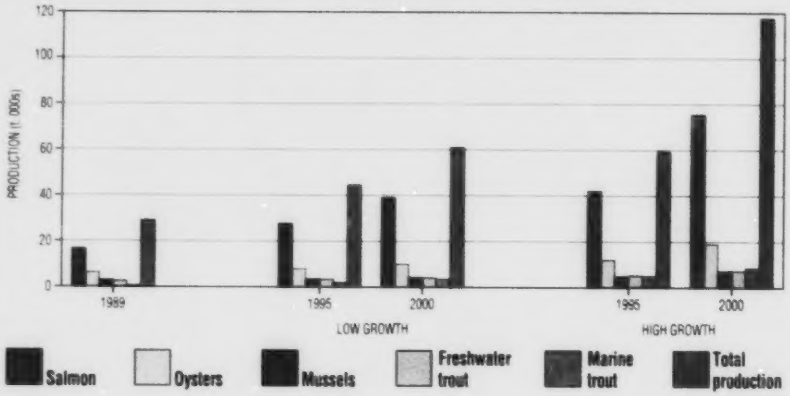
The parasitic sea lamprey invaded Lake Ontario from the Atlantic Ocean sometime during the 1800s and went on to invade the upper Great Lakes in the 1930s via the Welland Canal. By killing lake trout, lamprey contributed to the virtual extinction of the original stocks of this species in all the Great Lakes except Lake Superior. Chemical control of spawning streams has greatly reduced lamprey numbers. The lamprey probably never will be totally eradicated.

AQUACULTURE IN CANADA

Although protection and maintenance of wild stocks of fish will continue to be vital, there will be increasing emphasis on aquaculture in the coming decades as a major source of protein and as a business opportunity. Intensive aquaculture is already the major growth sector of Canadian fisheries. Total production in 1982 was 4 686 t, worth $13 million. By 1988, production was 22 000 t, valued at $100 million. Figure 8.13 shows some low- and high-growth projections to the year 2000 for salmon, oysters, mussels, freshwater trout, and marine trout.

FIGURE 8.13

Growth potential of Canadian aquaculture to the year 2000



Source: Department of Fisheries and Oceans.

Initially, the industry focused on oyster farming in British Columbia and the Maritime provinces and trout farming in Quebec and Ontario. The most important species today are Pacific and Atlantic salmon and mussels, but scallops, halibut, arctic charr, sablefish, and cod have unrealized potential. At present, research is being conducted on the growth, nutrition, genetics, physiology, and health of fish and on environmental impacts and the aquaculture potential of candidate species.

Major influences on aquaculture

One important reason for Canadian aquaculture's success to date is the availability of unpolluted marine and freshwater supplies. Clean water is an essential requirement for culture of all aquatic organisms. Filter-feeding shellfish such as oysters and mussels pick up whatever is in the water and therefore can become contaminated. Finfish such as salmon and trout are reared at high densities and must receive a continuous supply of well-oxygenated, clean water to reduce physical stress and carry away wastes.

Already, high background levels of metals and acidity in freshwater supplies have been limiting factors in farming of salmonids in certain areas. Cultured organisms are more susceptible to diseases than wild populations because of stress resulting from crowded conditions. Recent research and development have focused on methods to diagnose, prevent, control, and eradicate diseases. Inadequate sewage treatment in coastal areas will severely affect the developing shellfish industry, creating conflicts between licensed shellfish farms, the public, and government agencies.

Certain natural phenomena have adversely affected aquaculture, especially in coastal waters. The brown algae (*Heterosigma akashiwo*) killed large numbers of cultured salmon in British Columbia in 1986 and 1989. Seasonal blooms of toxic phytoplankton can be ingested by filter-feeding molluscan shellfish and can concentrate in the flesh of these species. Although the shellfish themselves are unaffected, they can cause serious illness or death when eaten by humans. Shellfish farming areas on both coasts are closely monitored as a result, and closures are applied if necessary. Mussel farms in Atlantic Canada, for example, were closed in 1987 because of domoic acid in cultured mussels from P.E.I.

All aquaculture operations in Canada depended initially on wild populations for broodstock or seedstock. In some instances, shortage of suitable wild stocks limited the growth of certain sectors of the industry during the early stages until industry developed its own capability for feedstock production (e.g., salmon farming in British Columbia and the Atlantic provinces). Farming of shellfish and such finfish as tuna, sablefish, and cod still depends to a large extent on natural sources for seedstock.

Potential environmental concerns

The rapid growth of the aquaculture industry has raised a number of potential environmental concerns, although many have not actually materialized. Water quality in the immediate vicinity of aquaculture operations may suffer, as surplus fish food and feces can cause enrichment of receiving waters through addition of excess nitrates and phosphates. There is also the potential for aquaculture facilities to pollute surrounding waters through release of other materials, such as plastic and paper waste and dead fish. These problems have been most frequently associated with marine farming on the Atlantic and Pacific coasts, and regulations are being developed to minimize these impacts.

There has been increasing pressure to transplant fish from one region to another and to introduce exotic species. There is concern that such movements would introduce diseases affecting both wild and cultured fish. However, there are rigorous regulations to prevent the importation and interprovincial transfer of infected fish. Escape of cultured fish could also affect genetic variability of wild stocks through interbreeding, and the cultured fish may displace indigenous species or stocks.

The Pandora's box of biotechnology will generate many concerns about the impacts of genetically engineered stocks on natural populations. Biotechnology has enabled genetic manipulation of stocks, including sex reversals, sterilization, and cloning. It is not known how such manipulated stocks may affect local populations. Researchers are addressing these issues as part of their assessment of environmental impacts of proposed aquaculture projects.

Aquaculture facilities can conflict with many other interests, such as navigation, commercial and recreational fishing, and sailing. Antifouling agents, antibiotics, and other chemicals used in aquaculture can accumulate in the flesh of cultured organisms or wild stocks close to culture facilities. Even if low levels of these substances are ingested with food, they can affect human health. Steps that have been taken to reduce the threat of chemical contamination include ceasing use of the antifouling agent tributyltin in aquaculture and prohibiting application of antibiotics and other drugs for a specified period prior to harvesting of fish.

Many of the potential environmental concerns have been avoided through management approaches. For example, there is increased scrutiny of proposals for the siting of aquaculture operations. Aquaculture products and processing facilities are subject to the same inspection requirements as for wild fish, to ensure safety for human consumption. There is monitoring of shellfish and shellfish-producing areas for toxicity (e.g., paralytic shellfish poisoning, domoic acid). As the development of the aquaculture industry continues, it will be necessary to continue monitoring the health of the farmed fish and to ensure that the appropriate environmental protection measures are in place.

CONCLUSIONS

Canada's marine and freshwater resources continue to supply an important part of the nation's food supply, and they sustain the economies of many coastal communities. Most of our surface waters remain productive and relatively unpolluted. However, wherever people live in numbers, and wherever there is industrial activity, notably around the Great Lakes and in coastal estuaries, fish stocks and their habitats are being threatened. High fishing pressure and habitat degradation are common in these areas.

Many oceanic fish stocks, on both the east and west coasts, were severely depleted prior to Canada's declaration of a 200-mile fishing zone in 1977. Although Atlantic groundfish stocks have recovered substantially since that time, many stocks continue to be subject to high fishing pressure, particularly the stocks that straddle the 200-mile limit, where foreign fleets ignore internationally negotiated catch limits, as well as certain domestic stocks, where Canadian fishers show disregard for recommended catch levels. Some fisheries are characterized by too many people chasing too few fish, and reduction of the fishing effort is needed to allow these stocks to recover. Other stocks are either in good condition or at historic highs and need continued good stewardship to conserve these resources into the future. The Northern Cod Review Panel (1990) and the Scotia–Fundy Groundfish Task Force (1989) have made a number of recommendations for restructuring certain fisheries and conserving certain stocks.

On the Pacific coast, salmon stocks appear to be near their historic high, although some individual stocks have suffered from overfishing and degraded habitats. A concerted effort has been made to enhance salmon production by releasing hatchery fish into salmon rivers.

The populations of various seal species have been increasing since the late 1970s due to the imposition of quotas and the collapse of fur markets. Pollution is a continuing threat to the endangered St. Lawrence beluga population, however, and stocks of bowhead whales, beluga, and walrus in the Arctic still show effects of historic overexploitation. An emerging northern problem is the impact of the long-range transport of chemical contaminants on fish species and marine mammals — and the humans who consume them.

Many of Canada's isolated stocks of freshwater fish are in good condition, whereas others close to human habitation are contaminated with toxic chemicals, and some species, like the blue walleye, have been driven to extinction. The long-range transport of airborne pollution contaminates even the most remote lakes. Acid rain is responsible for the destruction of habitat and loss of fish in thousands of lakes in eastern Canada, and many former salmon streams on the east coast are acidified.

Aquaculture can supplement natural fish stocks for food supply and provide much-needed economic benefits for coastal areas. The challenge will be to ensure that safeguards are in place so that the rapid growth of the industry does not damage the aquatic environment on which fish farmers and other resource users depend.

Canada's fisheries will continue to face a variety of pressures imposed by an increasing world population, which, on the one hand, will demand more food and, on the other, will produce more wastes that impair the natural productivity of oceans and inland waters. Managing the fisheries in the face of these pressures will require cooperation between various segments of industry and governments (federal, provincial/territorial, municipal, and foreign), as well as accurate and up-to-date information on the status of fish stocks and the ecosystems that support them. The current state of knowledge must be improved considerably to meet this need.

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9

COURTESY OF E.W. MANNING, OTTAWA

HIGHLIGHTS

Activity on Canada's farmland has intensified and become more specialized during this century, with larger farms, more area in crops, increased mechanization, and rising farm consolidation. These changes, coupled with the introduction of new crop varieties and management practices, have resulted in increased productivity. In some instances, however, these developments have been accompanied by increased environmental impacts, such as degraded soils, contaminated water bodies, and changing biodiversity.

■

In southern Ontario and the Prairie provinces, wetland habitat for waterfowl has been reduced by 68 and 71%, respectively, since European settlement, largely because of agricultural uses and drainage. Efforts like the North American Waterfowl Management Plan are helping to achieve a balanced use of agricultural landscapes.

■

Soil degradation by wind and water, salinization, and compaction continue to plague agricultural regions. To confront these problems, a number of federal and provincial soil and water conservation programs have been introduced. The sharp drop in the area of summerfallow in the prairies in recent years has reduced the risk of erosion by wind.

■

Organic matter content of soil has fallen 30–40% since the 1960s in eastern Canada and as much as 40–50% from presettlement levels in the prairies. This loss has led to an increase in fertilizer use to meet the nutrient demands of high-yielding crops. Commercial fertilizer applications quadrupled in tonnage between 1970 and 1985. Programs such as the Great Lakes Water Quality Initiative help overcome problems associated with inefficient fertilizer use.

■

From 1970 to 1985, the area of application of pesticides rose from 20% of cultivated land to over 50%. Excessive or improper application of pesticides has led, in some instances, to contamination of aquatic ecosystems. Integrated pest management schemes combined with technology to improve the application of pesticides are addressing this problem. Ontario's Food Systems 2002 program aims to reduce agricultural use of pesticides by 50% by the year 2002.

■

Agriculture must seek to become more environmentally sustainable. Governments at all levels are redirecting resources and devising programs that encourage farmers to be as good managers of the environment as they are of food production. Considerable progress has been made; however, continued effort is required.

■

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> "Every year brought spring... and every year the valley... had lain asleep under the snow for four months, offered man its fields to plough and harrow and fertilize and seed and harvest...
> ... different men...
> ... but always the same land."
>
> —Ringuet (1940)

INTRODUCTION

Almost all foods originate as natural products of the environment. Some wild plants and animals are removed from wilderness ecosystems at sea or on land by fishing, hunting, or gathering. Most, however, are cultivated by means of agriculture — one of the most widespread means by which human beings have learned to manage and adapt natural ecosystems in order to sustain human activity.

The practice of agriculture involves manipulating soil, water, and biological resources to produce enhanced varieties of selected plant and animal species in greater quantities than would normally occur in wild ecosystems. Agriculture has had a profound effect on local- to global-scale ecosystems and can also be profoundly affected by local to global environmental change. This chapter looks not only at the impact of farming on the environment, but also at the impact of environmental change on farming itself. It highlights agricultural policies and programs that are being introduced in response to environmental concerns. In addition, it discusses technological alternatives that are being developed to help farmers to protect the very resources on which farming depends.

THE EVOLUTION OF AGRICULTURE IN CANADA

For many centuries before the European discovery of North America, native people cultivated maize, squash, beans, and other crops in areas with suitable soil and climate. Starting in the 1600s, European colonists introduced mixed farming, involving livestock and crops. Although productivity was low, agricultural output was relatively stable and utilized existing resources without recourse to substantial added inputs. Some of the crops went to feed the livestock; manure from the livestock was returned to the land.

Early farming in Canada was primarily a subsistence activity, producing food for the individual households concerned. The first European settlers initiated a process of massive land-use change. Lumbering and agricultural activities soon affected the environment. It was difficult to adapt European farming techniques to the harsh and hostile conditions. It took much effort and time to develop productive farmlands out of forested and prairie expanses.

Commercial agriculture grew slowly at first and mostly in response to local market opportunities. These opportunities expanded as the timber trade brought more people to the Great Lakes –St. Lawrence basin, and the forests disappeared from land that turned out to be well suited for agriculture.

With the completion of the Canadian Pacific Railway in 1885, settlers streamed westward to populate the prairies. The introduction of Marquis wheat in 1909 and the development of the fallow rotation system enabled wheat to be successfully grown in the prairie climate. The initial basis of the agricultural economy in the west was established. By 1931, 60% of Canadian grasslands were under cultivation (Rowe and Coupland 1984).

Urban growth, spurred by the development of manufacturing, resulted in the expansion of markets for food products. Before 1900, the typical Canadian farm had been about 40 ha in area. Farming was horse-powered and labour-intensive. By 1921, the average Canadian farm size had doubled to 80 ha. The shift from animal to steam and then to internal combustion power allowed more land to be managed by individual farmers. In 1941, the average farm size had reached 96 ha (Fig. 9.1). Farm productivity was on the rise, but so were the costs of production. Average farm size doubled to 187 ha by 1971 and in 1986 reached 232 ha (Statistics Canada, 1986 Census of Agriculture).

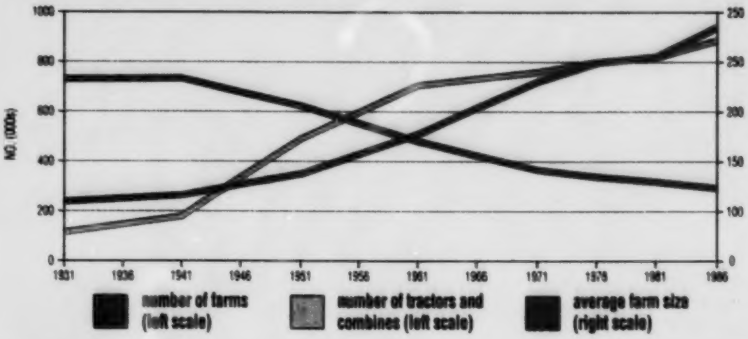
As the average farm size increased, the number of farms decreased. For example, in 1941 there were 732 832 farms across Canada; by 1986, the number was 293 089 (Fig. 9.1). Today, farmers comprise less than 4% of the national workforce, compared with 20% in 1951 (Statistics Canada, 1951–81 Census of Canada).

Small, mixed farms evolved to larger, more specialized operations. Ninety-nine percent of these production units are still family-oriented farm businesses. The trend to larger, more specialized operations had the effect of concentrating more production on a smaller percentage of farms. By 1986, 39% of farms contained 63% of Canada's farmland (Statistics Canada, 1986 Census of Agriculture). Eight percent of all farms growing wheat contained 31% of Canada's wheat acreage. Forty-three percent of Canadian dairy cows were found on 18% of the dairy farms. A dramatic illustration is egg production. In 1966, 90% of eggs came from 28% of the farms reporting this activity. By 1986, 95% came from a mere 13% of egg-producing farms.

Along with farm expansion and consolidation came the trend towards greater specialization. Between 1976 and 1986, the area of wheat in Alberta, Saskatchewan, and Manitoba — which together produce 97% of all wheat in Canada — increased almost 30%, from 10.9 million to 13.8 million hectares (Statistics Canada, 1976 and 1986 Census of Agriculture). In central Canada, new short-season corn hybrids accelerated crop specialization during the 1960s and 1970s. The acreage in corn in Ontario and Quebec more than tripled between 1961 and 1986. In Ontario, which currently produces three-quarters of Canada's corn, corn occupies more farmland than any other crop apart from perennial forages.

The shift from mixed farming to specialized systems has led to increased productivity and efficiency, but it also exacts an environmental price. For example, corn production was linked, until recently, to the acceleration of soil degradation (e.g., loss of soil organic matter, soil compaction, and increased soil erosion); however, in the last few years, better management practices have largely overcome these negative effects.

Number of farms, average farm size, and number of tractors and combines in Canada, 1931–86



Source: Statistics Canada (1986a, 1986 Census of Agriculture).

In addition to intensified agricultural practices, other pressures, such as urbanization, are stressing the land base. Urbanization is also changing the pattern of farm ownership. Many farmers now view rental as an alternative to the high cost of purchasing land. On some of the country's best agricultural land, near Montreal, Toronto, and Winnipeg, the proportion of rented farmland reaches or exceeds 50%. This trend raises a number of concerns about land management, because improvement practices that are worthwhile to a landowner may be less attractive to a short-term leaseholder.

While Canadian farmers have been working hard to increase their productivity in the face of economic and other pressures, the inherent productivity of the land has been declining in some areas. The remainder of this chapter examines modern agricultural practices, their environmental impacts, and the efforts of governments and farmers to address these concerns.

AGRICULTURE'S NATURAL ENDOWMENT

Land

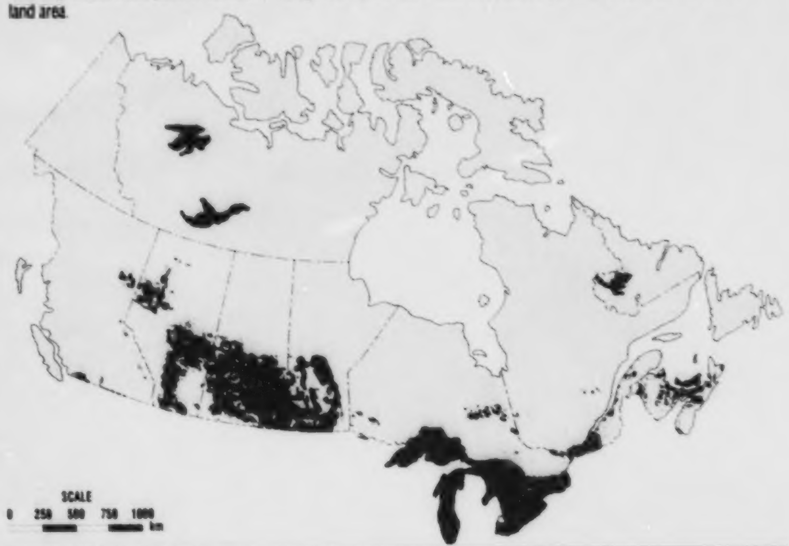
Canada's 10 provinces comprise 543 million hectares, of which 68 million hectares (about 13%) was agricultural land in 1986 (Statistics Canada, 1986 Census of Agriculture). As Figure 9.2 shows, however, not all provinces are equally well endowed with good farmland. Saskatchewan possesses the largest amount of prime agricultural land, followed by Alberta, Ontario, and Manitoba, respectively (Fig. 9.3). Nationally, the total area of farmland is about the same as it was during the 1930s (Fig. 9.4). However, there have been some significant regional shifts in recent decades. Generally, increases have been greater in the Prairies and lesser in British Columbia and Newfoundland. Significant decreases have occurred in Ontario, Quebec, and the Maritimes.

Although the overall quantity of farmland has remained relatively constant, improved land (i.e., area under crops, improved pasture, summerfallow, and other improved land) is gradually occupying a greater proportion of the total area. In particular, cropland (i.e., area under crops and summerfallow) has increased 41% since 1931. A marked acceleration since 1976 shows how farming activities have intensified, partly at the expense of unimproved land: woodland, for example, has decreased on censused farms by about 70% since World War II.

FIGURE 9.2

Canada's prime agricultural land

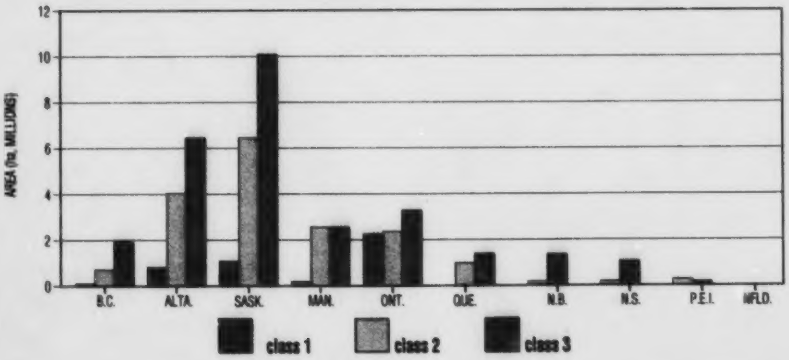
This map shows those parts of Canada where agricultural land in classes 1, 2, and 3 represents 40% or more of total land area.



Source: Environment Canada (1976).

FIGURE 9.3

Distribution of prime agricultural land, by province



Source: Environment Canada (1976).

Urbanization of land

Because it threatens the sustainability of agriculture in key agricultural regions, urban encroachment on agricultural lands is a serious concern. In 1986, about two-thirds of Canada's population lived in 70 "urban-centred regions" with populations over 25 000 (Warren *et al.* 1989). Between 1966 and 1986, urbanization claimed over 300 000 ha of rural land in these regions, 58% of which had been prime agricultural land. Figure 9.5 shows how the loss of agricultural potential in these 70 regions was distributed among the provinces.

At the current rate, it would take 70 years to convert 1% of prime agricultural lands to urban uses. Although seemingly slight in national terms, the land losses have been concentrated in some of the best agricultural regions, including the Fraser River valley in British Columbia, the St. Lawrence lowlands of Quebec, and the Edmonton–Lethbridge corridor in Alberta. In Ontario, prime agricultural lands (classes 1–3) accounted for 83 040 ha (78%) of the area of rural land that disappeared between 1966 and 1986. In particular, in southern Ontario, Canada's largest concentration of class 1 farmland is under constant pressure from a large and growing population.

In short, the quantity of land that is converted from agricultural to urban uses is less important than its quality. The loss of the best land means the loss of soils with the highest potential for producing varied crops both now and in the future. Furthermore, it forces some farmers to cultivate soils with lower productive capability, using methods that cost more and cause more environmental stress.

Weather and climate

Natural variations

Fluctuations in weather patterns, along with natural climate variations, have always been significant factors in determining an area's suitability for farming. Monitoring these fluctuations, taking into consideration their impact on various types of agriculture, provides information required for good land stewardship.

Drought is a normal component of the climate in semiarid regions, such as southern Saskatchewan. Here, overgrazing can lead to loss of perennial ground cover and replacement of desirable native or cultivated forage species by weeds. In the absence of adequate cover, wind and water may cause serious erosion of topsoil. In this region, wheat growers experience frequent drought-related crop losses. For example, in 1988, a year of summer drought conditions, crop yields were only about 61% of what they had been in 1987, a year of average yield for the 1980s. In Saskatchewan alone, the wheat yield dropped by more than half. Satellite images taken in the two successive years (Fig. 9.6) provide a dramatic illustration of this change.

One way to alleviate the effects of drought is to return marginal land in the most arid parts of the prairies to grassland and community pastures. The latter activity began in earnest with the introduction of the Prairie Farm Rehabilitation Administration in the 1930s (Gray 1967). Today, the Permanent Cover Program in the prairies, a part of the National Soil Conservation Program, encourages farmers to plant marginal land in perennial forage plants and/or trees, instead of annual crops. Such changes help conserve soil moisture, reduce runoff, restore natural habitat, and remove land with unreliable yield capability from the agricultural resource base. The opposite extreme, an excess of water, can also hurt the agricultural sector, notably in parts of eastern Canada and in the Fraser River valley of British Columbia. Spring snowmelt may result in increased erosion rates and runoff, leading to peaks in nitrate concentrations in surface water during certain periods. Overly wet soils may delay spring sowing and seed germination or make harvesting difficult in the fall. Heavy rainfall and low capacity of the soil to absorb moisture make it more likely that pesticides and fertilizers will be lost in runoff. By integrating climatic and agronomic data, farmers can reduce their use of chemicals and help promote sustainable production practices.

Climatic change

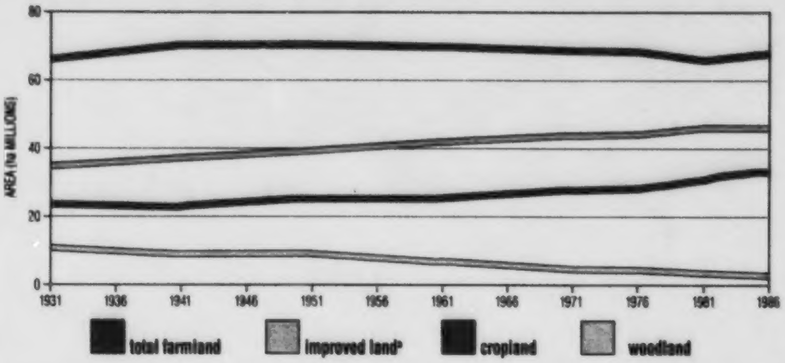
Human activities are changing the Earth's atmosphere at an unprecedented rate (see Chapter 22), by increasing the concentrations of "greenhouse gases": carbon dioxide (responsible for about 50% of the greenhouse effect), methane, CFCs, nitrous oxide, and tropospheric ozone. Increases in these trace gases will enhance the greenhouse effect, resulting in a warming of the Earth's surface.

Current global general-circulation models predict an increase in global temperature of about 0.3°C per decade if no steps are taken to reduce emissions of greenhouse gases to the atmosphere (Intergovernmental Panel on Climate Change 1990). This would result in a mean global temperature increase of 1°C above the present value by 2025 and 3°C before the end of the next century. On the other hand, if emission controls are put in place, then the increase in global temperature would be reduced to 0.1–0.2°C per decade. Regional climatic changes differ from the global mean, and they are difficult to predict. Consequently, this report will only outline in general terms what can be expected for the agricultural sector.

Although many uncertainties exist with respect to changes in climate, the implications for agriculture in Canada are becoming better understood. For example, for each 1°C warming of the average growing season, the average frost-free period will increase by 7–10

FIGURE 9.4

Trends in the amount of agricultural land, 1931–86



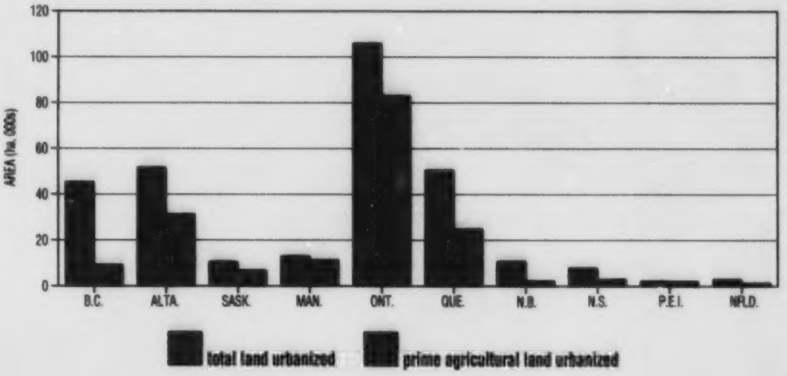
[a] Improved land = area under crops, improved pasture, summerfallow, and other improved land.

Source: Statistics Canada (1986*a*, 1986 Census of Agriculture).

FIGURE 9.5

Urbanization of farm land, 1966–86

The area of rural land and prime farmland in 70 urban-centred regions that was lost to urban growth.



Source: Warren *et al.* (1989).

[illegible]

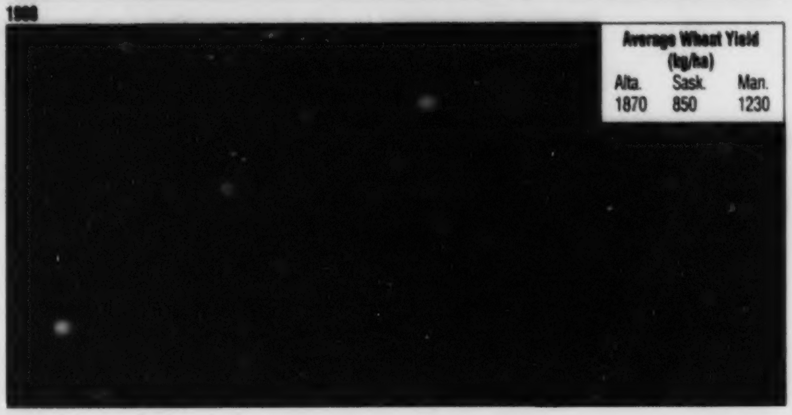
Comparison of prairie crop conditions, 1987 and 1988

The red on the satellite images corresponds to vigorous growth of vegetation, and the blue shows drought-affected areas. Both images were taken in early August.

1987

Average Wheat Yield (kg/ha)		
Alta.	Sask.	Man.
1970	1850	2010

1988



Average Wheat Yield (kg/ha)		
Alta.	Sask.	Man.
1870	850	1230

Source: Statistics Canada, Agriculture Division; Energy, Mines, and Resources Canada, Canada Centre for Remote Sensing; Agriculture Canada (1989).

days (Williams *et al.* 1988). The quantity of heat available for crop growth will also increase with increase in average growing season temperature (Bootsma *et al.* 1984). This would have a significant impact on the range and distribution of crops grown in Canada (Stewart 1986). In some cases, higher-yielding varieties that require a longer growing season could be grown; in others, farmers might adopt entirely new crops. The temperature increase would also allow agriculture to move gradually northwards, subject to limitations in soil and physiography. Additionally, an increase in atmospheric carbon dioxide could contribute to increases in crop yields.

On the negative side, changes in rainfall and evaporation patterns could intensify some existing problems. For example, some scenarios predict significantly warmer, drier conditions for the southern prairies (Manabe and Wetherald 1986). Should this happen, the frequency and severity of drought would increase. The impact of drier conditions could also accelerate or exacerbate wind erosion, salinization, and loss of organic matter. Warmer, longer growing seasons could also mean that pests and diseases normally found farther south would move northwards.

Clearly, climatic change will have an impact on soil and water resources; on the types, varieties, and distribution of crops grown in Canada; and on livestock production. Adaptive innovations in technology and methods in the agricultural industry will be required. Agricultural activity may decline in some regions, while expanding in others.

Agriculture also contributes to climatic change. Degradation of soil organic matter due to poor soil management is responsible for some of the increase in carbon dioxide in the atmosphere. The use of fossil fuels in production, transportation, and manufacturing phases of the agri-food sector also adds carbon dioxide to the atmosphere. Cultivation and increased use of fertilizers lead to emissions of nitrous oxide (N_2O). Manure and enteric fermentation in cattle have been cited as significant sources of methane. Globally, it is estimated that agricultural sources are contributing 14% of the increase in greenhouse gases (Intergovernmental Panel on Climate Change 1990). Efforts are being made to understand the various processes involved in the cycling of greenhouse gases with the aim of increasing the capacity of agricultural soils to act as a carbon (in the forms of methane and carbon dioxide) sink, while at the same time reducing the sector's contribution to the increase in greenhouse gases.

Biota

The traditional focus of agriculture has been primarily on species of farm animals, crop plants, and their pests, most of which are not native to Canada. In recognition of the importance of interactions between agriculture and the environment, it has become increasingly evident that agriculture must take account of the role that all Canadian biological resources can play in sustainable agriculture and in sustaining the environment.

Many of Canada's least-known groups of organisms perform essential environmental tasks. Some, such as bacteria and fungi, break down organic matter and minerals, making nutrients available in soil and water. Others, such as insects, pollinate flowering plants or control populations of pest species. Insects, arachnids, plants, and fungi are particularly sensitive to environmental variation and are quick to react to habitat change, climatic variation, and other environmental stresses. Many can be termed "indicator species"; careful documentation of extensions or contractions in their distribution is a convincing and cost-effective way of measuring environmental change.

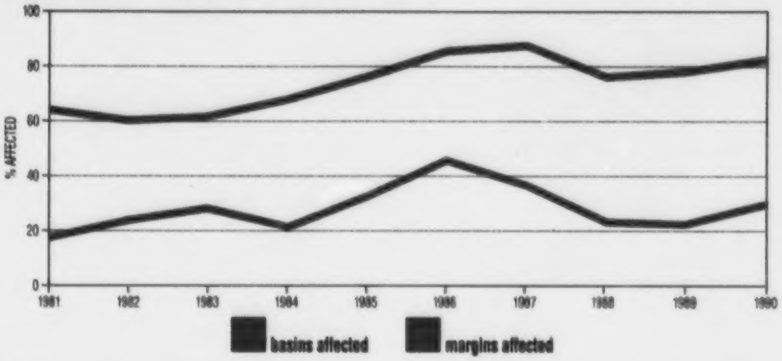
Wildlife and wildlife habitat

Generally speaking, the quantity and quality of wildlife habitat in Canada have been degraded by settlement and agricultural development. Although farmlands and rangelands do provide enhanced habitat for certain species (a number of which cause extensive damage to orchards and standing crops), others have declined as a direct result of agricultural expansion and production practices. Many species of native plants, reptiles, fish, birds, and mammals are endangered or threatened as a consequence of habitat loss to agriculture (Burnett *et al.* 1989).

In the prairies, agricultural expansion has been the major force in eliminating 71% of wetlands since settlement (Environment Canada 1986), resulting in significant declines in waterfowl populations. Figure 9.7 illustrates the proportion of prairie ponds whose basins or margins were affected by agricultural practices over a 10-year period. For example, in 1990, 30% of wetland basins and 82% of margins in the Prairie provinces were influenced by farming activities such as clearing, drainage, grazing, haying, and cultivation (Caswell 1990). In Ontario, south of the Canadian Shield, 68% of presettlement wetlands have been lost, primarily to agricultural development (U.S. Department of the Interior and Environment Canada 1986; Snell 1987; Clarke *et al.* 1989).

Agriculture has so modified the original ecosystems that there is growing concern for their continued viability and the survival of the species that are peculiar to these areas. Wildlife habitat within agricultural areas must be conserved and enhanced to sustain a wide diversity of plant and animal species. There is a growing recognition within the farming sector that agriculture can coexist with wildlife, and that direct benefits accrue from maintaining and enhancing wildlife habitat. For example, farm shelterbelts and woodland habitat may attract predators that feed on agricultural pests. Retention of wetlands on farms not only maintains habitat but conserves groundwater resources and provides a measure of protection against drought.

Percentage of prairie ponds with margins or basins affected by agricultural practices, 1981–90



Source: Caswell (1990).

Vascular plants

The latest compilation of vascular plant species of Canada (Scoggan 1978–79) lists 4 153 named species as indigenous or established. Modern farming methods affect plant diversity in new ways. Traditionally, the planting of small plots in various landscapes created a variety of transitional habitats, which tended to promote plant diversity. Indeed, the agricultural influence on vegetation has been considered by many to have an enriching effect. In the last few decades, however, this enhancement of diversity has been reversed (Hampicke 1978).

Agriculture today reduces species diversity among plants by attempting to create moist and nutrient-rich soil conditions wherever possible, thereby reducing environmental variety. In Canada, about 50 plant species are currently considered to be significantly endangered, and there is concern for the status of another 500 (Haber 1986).

Among the plant species introduced into Canada by humans, more than 500 are considered to be agricultural weeds (Crompton *et al.* 1988). Curiously, many agricultural crops themselves evolved from weeds. Agricultural practices have been responsible for the importation of many of these weeds as impurities in seed grain. But not all weeds are pests. Some are beneficial, stabilizing soils to reduce erosion and providing seeds, food, and shelter for wildlife. At least one weed of Canada is actually incorporated into an alternative agricultural system: black medick has recently been found to be an excellent rotational plant that enriches the soil while discouraging other weeds. Nevertheless, competition from aggressive, imported weed species and the tendency to control weeds in agricultural environments have disturbed the natural diversity of native plants.

Microorganisms

Microorganisms are the most numerous and varied of all living things. One well-known group is the fungi, represented in Canada by some 11 000 species. Some, such as mushrooms, are deliberately cultivated as cash crops. Some are used as biological control agents. Others convert raw materials into food. Many help in disease control by producing antibiotics, and the toxicity of others can cause disease. Among fungal plant pathogens, the grain rusts are the most notorious. The presence of fungi, in conjunction with other microorganisms such as bacteria, contributes to soil quality.

Many agricultural practices, such as tillage, fertilization, and pesticide applications, influence the fungal and microbial population of the soil. Reductions in microbial biomass have a negative effect on the mechanical stability of soils, making them more prone to erosion and compaction.

Insects and arachnids

Terrestrial arthropods, mainly insects, spiders, and mites, are extremely diverse in Canada, with an estimated 66 000 species (Danks 1979). Many are beneficial to agriculture and the environment, whether as pollinators of crop plants and fruit trees or as food for certain species of birds. Some insects are themselves valuable predators of agricultural and forest pests.

Insects and mites in soil and water are effective bioindicators of environmental conditions. Changes in their diversity, density, and distribution can point to stress in an ecosystem. Even a seemingly minor disturbance, such as converting grassland to cultivated cropland for one season, can disrupt species diversity so much that it will take over 25 years to recover.

Genetic resources

Pressures against fragile ecosystems have induced an ongoing decline of the world's genetic resources. Many of these pressures, such as agricultural technology and urban development, are direct results of human activity; others result from global climatic and environmental influences, which may stem from human activities or natural phenomena.

Selective breeding for high performance and uniformity has significantly narrowed the genetic base of animals, plants, and microbes used in agriculture. The resultant loss of germplasm (genetic material including genes) is of worldwide concern. Current varieties resulting from crop breeding have been designed for optimum performance and yield under carefully managed growing conditions. Preserving a broad genetic base for crop species will be essential if breeding programs are to develop varieties that can survive changing environmental and pest conditions. None of our major cultivated crops or their wild relatives is indigenous to Canada.

The preservation of germplasm resources of animals used in agriculture in Canada is also of concern. Unfortunately, at the present time, there is no organized program to sample, evaluate, utilize, and preserve animal genetic resources, although efforts are being made in that direction. As for microorganisms, the availability of a large number of strains of bacteria, fungi, and yeast is essential to the future of biotechnology.

AGRICULTURAL PRODUCTION AND THE ENVIRONMENT

This section describes not only the environmental degradation that can result from agricultural production, but also some constructive programs that help to mitigate this damage and conserve soil and water. Also discussed are irrigation and drainage and the use of summerfallow, which are important agricultural activities that can have adverse environmental consequences.

Land degradation processes

In the previous state of the environment report for Canada, several land degradation processes were described in detail (Bird and Rapport 1986). Since then, more information on the physical, economic, and environmental effects of these processes has been gathered, and strategies and policies have been put in place to mitigate land degradation and its environmental consequences.

Soil erosion

Soil erosion by water and wind is the most widespread soil degradation problem in Canada. When rainfall and snowmelt exceed the rate at which water can infiltrate the soil, the runoff of excess surface water can cause sheet, rill, or gully erosion. Organic matter and fine clay mineral particles are removed and are often transported to waterways, causing problems of sedimentation — and pollution, too, if fertilizers and pesticides are present in the topsoil. Topsoil loss reduces productivity.

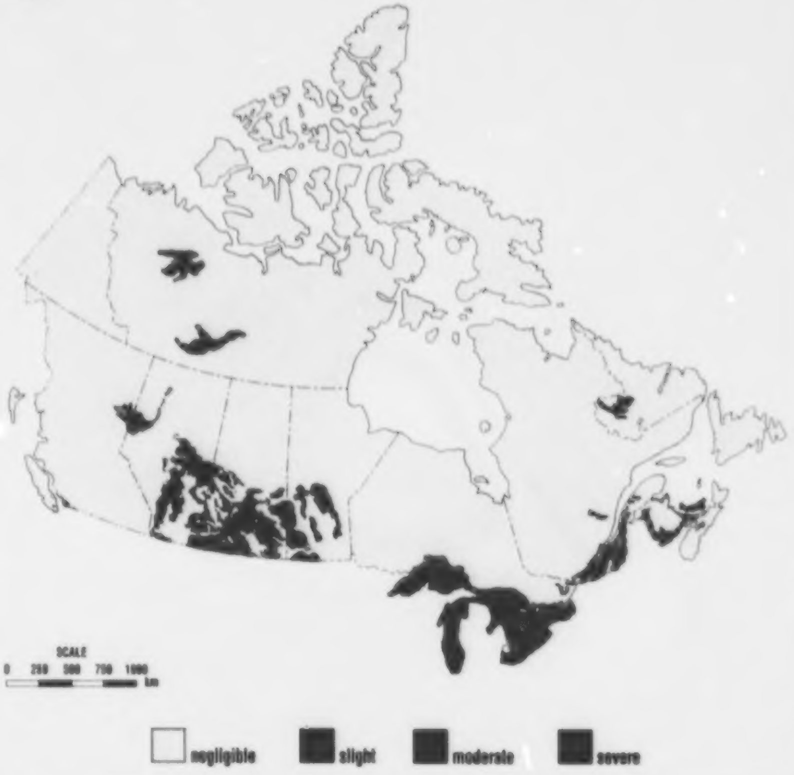
Soil erosion by water varies widely across Canada, depending on climate and precipitation, soils and landforms, and land-use practices. The extent and severity of water erosion across the country are illustrated in Figure 9.8.

Soil losses of less than 5 t/ha per year are generally difficult to see in the field. Depending on soil type and depth, losses exceeding 5–10 t/ha per year can represent a potential for long-term damage to farm productivity (Dumanski *et al.* 1986). In fact, any soil loss beyond the natural rate of soil formation (0.5–1.0 t/ha per year) will eventually reduce the quality of the soil.

In British Columbia, erosion measurements in the Peace River area have recorded losses of up to 14 t/ha per year on summerfallow (Van Vliet *et al.* 1983). Erosion losses as high as 30 t/ha per year have occurred in the Fraser Valley under row crops (Sprout 1984). In Saskatchewan and Alberta, soil erosion by water accounts for between 40 and 50% of total soil erosion and affects almost 5 million hectares of agricultural land. In Ontario, water erosion is most severe in the southwestern region, where estimates suggest that yields may sometimes be cut by as much as 40% (Battison *et al.* 1984). In Quebec, water erosion is a problem where row crops are planted on fine-textured soils and on the rolling land-

[illegible]

Estimated extent and severity of erosion by water on agricultural land



Source: D.R. Coote, Agriculture Canada, personal communication.

scapes of the Eastern Townships. In Atlantic Canada, potato lands have some of the worst water erosion problems (Chow and Daigle 1986). In Prince Edward Island, losses of up to 20 t/ha per year are common (Himelman and Stewart 1979).

Soil erosion by wind is associated with high wind speeds, dry surface soil conditions, and cropping practices that leave the soil unprotected. Excessive tillage and summerfallowing of large fields unprotected by windbreaks can produce an extreme wind erosion hazard. Even under relatively humid conditions, sandy soils and powdery organic soils may be vulnerable.

Blowing soil is abrasive, damaging buildings, machinery, and vegetation. Airborne nutrients and pesticides may eventually degrade water quality and aggravate health problems in downwind areas. Soil erosion from wind is estimated to be severe in parts of southern Manitoba and Alberta and in a large part of Saskatchewan (Fig. 9.9).

Table 9.1 shows estimates of the economic impact of water and wind erosion in Canada — between $484 million and $707 million per year in reduced yields and higher costs. If control measures are not introduced, erosion in excess of soil formation rates eventually leads to serious soil depletion. The damage caused by agricultural soil erosion may be as costly off the farm as it is on the farm (Agriculture Canada 1985). In Ontario, sediment damage from agricultural lands is estimated to cost about $100 million annually. The problems caused by eroded soil particles washing into waterways have been described (Switzer-Howse and Coote 1984) as follows:

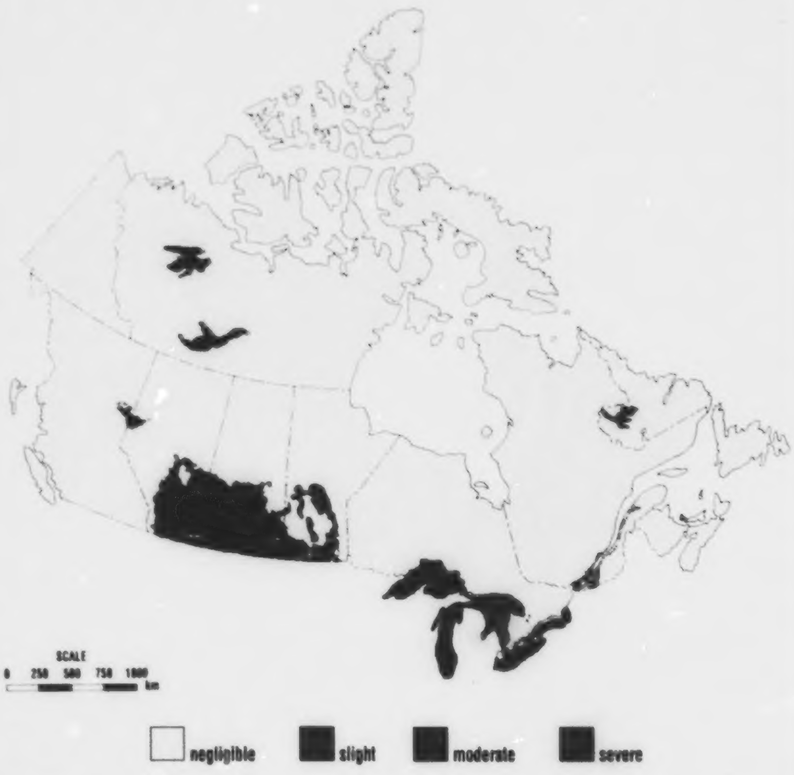
- channel capacity reduced by silt accumulations
- fish habitat altered and destroyed
- plant and algal growth accelerated by excess nutrients
- buildup of heavy metals, pesticides, and other toxic substances
- recreational values lowered
- costs to render water fit for human consumption increased.

Sediments lower water quality by binding and transporting phosphorus, heavy metals, pesticides, and other pollutants. For example, phosphorus bound to soil particles eroded from cultivated land has been shown to account for the bulk of the phosphorus pollution in farmland runoff in the Canadian part of the Great Lakes basin (Switzer-Howse and Coote 1984). Phosphorus causes excessive growth of plants and algae in streams and lakes. However, much of the total phosphorus is bound so tightly to sediment that it is not readily used by these plants.

Pesticides currently used are generally not transported by eroded sediments to the same degree as were the more persistent pesticides that were widely used in the 1950s and 1960s. Although DDT is not used anymore, it can still be detected in soil eroding from agricultural areas in the Great Lakes basin (see Chapter 18). Nonetheless, some pesticides in use today do reach streams and lakes in eroded sediments. Research is currently under way to determine how much of a threat these materials pose to surface waters, and to the Great Lakes in particular.

Selenium, arsenic, heavy metals (e.g., mercury, lead, and cadmium), and toxic organic compounds (e.g., PCBs) reach farm fields through industrial pollution,

Estimated extent and severity of erosion by wind on agricultural land



Source: D.R. Coote, Agriculture Canada, personal communication.

Estimates of the annual on-farm economic impact of water and wind erosion

Region	Water erosion estimates ($, million)	Wind erosion estimates ($, million)
British Columbia	17–24	2
Prairie provinces	155–197	213–271
Ontario	68–157	1–8
Quebec	5–17	2
Atlantic provinces	21–29	*
Canada	**266–424**	**218–283**

* = insignificant, except for Prince Edward Island, where annual impacts have been estimated to total $100 000.

Source: Dumanski *et al.* (1986).

atmospheric deposition, and applications of sewage sludges. Bound to sediments, these compounds move from agricultural lands to surface waters. Soil management practices cannot prevent the contamination, but control of erosion can help reduce the movement of heavy metals and toxic organic compounds off the land and into streams and lakes (Switzer-Howse and Coote 1984). Levels of mercury and PCBs detected in fish in the Great Lakes and other freshwater systems are high enough that some species are unfit for human consumption.

Although wind erosion also contributes sediments to water, it has a greater impact on air quality. The "Dirty Thirties" were a time of unprecedented air pollution, resulting largely from wind erosion in the prairies. Since then, less droughty conditions have generally prevailed, and many farmers have adopted practices to reduce wind erosion. However, in the past decade, drifting soil has again become a serious, if intermittent, problem, caused by drier conditions and a relaxation of control measures such as strip cropping and the planting of windbreaks.

Compaction

Soil compaction is a common problem in the lower Fraser River valley of British Columbia and in parts of central and eastern Canada (Fig. 9.10). Dumanski *et al.* (1986) estimated that the annual cost of compaction to Canadian farmers was between $68 million and $200 million (Table 9.2).

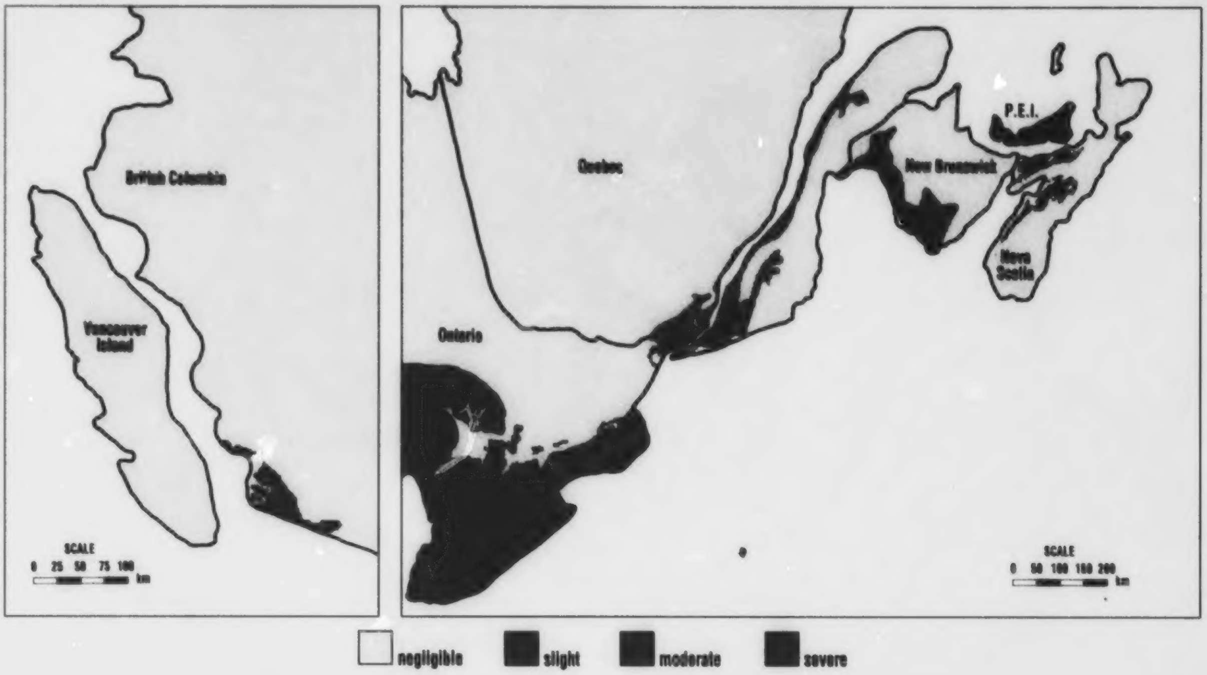
Frequent field traffic under moist conditions and intensive tillage with heavy machinery can change a naturally friable, well-aerated soil to one in which air and water movements are restricted. Compacted soils are often prone to erosion by water because the denser soil structure impedes the infiltration of rainfall and snowmelt.

Clay soils and soils low in organic matter are particularly vulnerable to compaction. Furthermore, field crops such as potatoes, corn, soybeans, and sugar beets are often associated with compaction because they require long growing seasons and thus must often be planted in the early spring and harvested in the fall when the soil is too moist. Because compaction is often associated with crops that are grown in rotation management systems, compaction is a cyclical phenomenon. The compacted layer may be much less evident during years when these crops are replaced with cereals or forage crops.

It has been estimated that crop yields can be reduced by up to 60% when soils are severely compacted (Fox and Coote 1986). Roots penetrate compacted soil with difficulty, the rooting zone is restricted, and the plant experiences moisture and nutrient stress.

FIGURE [illegible]

Estimated extent and severity of soil compaction on agricultural land



Source: D.R. Coote, Agriculture Canada, personal communication.

TABLE 9.2

Estimates of the annual on-farm economic impact of soil compaction

Region	Estimate ($, millions)
British Columbia	6–12
Prairie provinces	*
Ontario	21–71
Quebec	30–99
Atlantic provinces	11–18
Canada	**68–200**

* = insignificant.

Source: Dumanski *et al.* (1986).

Acidification

Soil acidity is widespread in Canada, particularly in areas with relatively high rainfall. Acidity generally reflects natural soil conditions, such as acidic parent materials and decomposition of accumulated plant residues. The effect of acid rain on soil acidification in farmland is estimated to be less than that of fertilizer (see Chapter 24). The application of fertilizers, especially those containing nitrogen and sulphur, contributes to acidification in sensitive soils. When soil pH drops below 5.5, crop yields decline. Farmers commonly apply lime to acidic soils to maintain a satisfactory soil pH.

Some environmental effects of acidified soils are known. The solubility of iron and aluminum, as well as some trace elements and pesticide residues in the soil, is increased by soil acidification. There is some concern that these dissolved materials may leach into water resources at levels high enough to have negative environmental effects.

Loss of soil organic matter

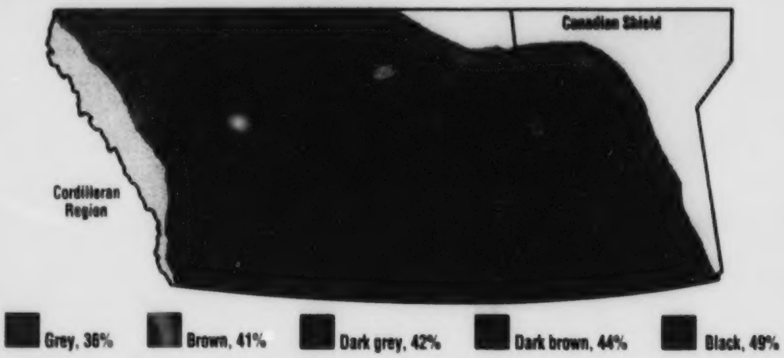
Organic matter contributes to a stable, well-aggregated soil structure that is essential for high water infiltration, well-aerated root zones, and good bearing capacity for machinery. It also contributes to nutrient and moisture retention, provides nutrients for crops when it decomposes under the action of soil microorganisms, and provides cation absorption capacity. The amount of organic matter in soils is dependent on the balance between formation and decomposition.

Soil organic matter consists of plant, animal, and microbial residues at various stages of decomposition, the microorganisms themselves, and the more resistant soil humates. In agricultural systems, an equilibrium is eventually reached when the addition of organic matter from residues makes up for the losses through chemical and biological degradation. This equilibrium is also affected by the quantity of nutrients removed with the harvest and by inputs of natural and synthetic fertilizers.

Figure 9.11

Losses of organic matter in the prairies, by soil zone

The percentage losses apply to the topmost or "A" soil horizon.



Source: McGill *et al*. (1981).

When agricultural development converted the prairies from grassland to cereal production, the export of nutrients by crops, tillage, and erosion resulted in a loss of about 40–50% of the original soil organic matter (Fig. 9.11). In areas of intensive cultivation in central and eastern Canada, the level of organic matter in soils is 30–40% lower today than it was under the forage rotation system that was common until the 1960s.

Organic matter in the soil performs many environmental roles. For example, when plant residues are returned to the soil, some of the carbon they contain is immobilized until it is returned to the atmosphere as carbon dioxide. Cultivation speeds the process of oxidation of organic material and hence the release of this greenhouse gas. Also, organic matter has a larger retention capacity than mineral particles for many chemicals and therefore helps reduce groundwater contamination by nutrients and some other contaminants. Further, through its effect on soil structure, it helps control soil erosion.

Irrigation

Irrigation, as a means of optimizing the productive capacity of land, is most often associated with fruit, tobacco, and vegetable production in eastern Canada, and with forage, cereal, and oilseed crops in the west (Shady 1989). The use of irrigation in Canada has been steadily increasing. Figure 9.12 shows that the total irrigated area more than doubled, to almost 900 000 ha, between 1970 and 1988.

Irrigation may have both negative and positive effects. Reservoir construction may result in the flooding of forests and agricultural lands, the flooding of scenic rivers, and the destruction of historically or culturally important sites. Habitat for fish and wildlife may also be lost. Reservoir construction and irrigation systems can alter the flow and water quality of a river, often to the disadvantage of downstream users. Deposition of sediment can occur in reservoirs, and streambed erosion may occur below a dam. These processes can alter flooding patterns, diminish water quality, and harm fish populations. Water fluctuations from reservoir regulation can also destroy waterfowl nests and homes of water-dwelling mammals, such as beavers and muskrats.

Environmental concerns related to irrigated land result from the often greater use of pesticides and fertilizers than is usual under dryland conditions. Residues from these materials may move into streams via irrigation return flows or be leached into groundwater. Salinization and the subsequent leaching of salts from irrigated soils can also occur. Lands adjacent to unlined canals have become saline and unproductive when water tables were raised in areas where salts were present in the subsoil.

Streams receiving return flows may also experience higher levels of dissolved salts. These tend to decrease with time, but are of particular concern where dilution is inadequate because of drought or minimal stream flows.

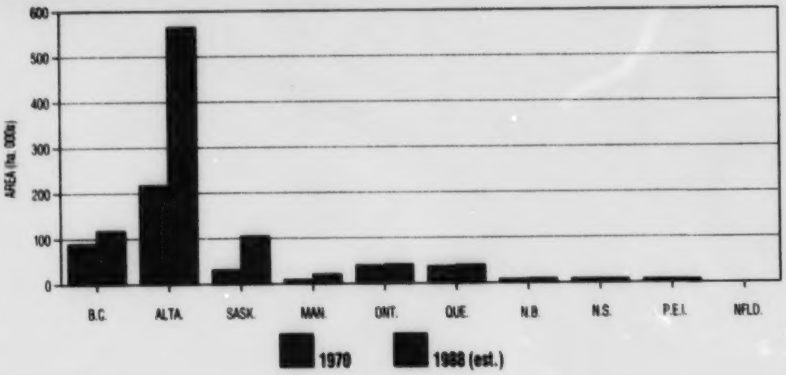
On the other hand, the construction of water storage areas can produce benefits, particularly in those parts of the prairie region where surface waters are scarce. Besides providing water for irrigation, these impoundments provide new types of wildlife habitat and can be used for fishing and recreation. Irrigation projects may contribute to increases in wildlife populations in other ways as well. Brush and weeds often grow in abundance along canals and fence lines, providing excellent cover for birds and small mammals. In recent years, however, increased chemical control of brush and weeds and the trend towards canal lining and the use of pipelines have tended to diminish the positive effects of irrigation developments on wildlife populations.

Drainage

Subsurface drainage is widespread in eastern Canada and parts of British Columbia as a means of removing water from naturally saturated subsoils. The practice improves soil aeration and permits more timely cultivation with reduced damage to soil structure. Indeed, in many areas crop production would be impossible were it not for subsurface and/or channel drainage. Table 9.3 shows the estimated area drained by surface and subsurface drainage techniques in each province, as well as the additional land areas in each province that could be drained for the benefit of agriculture. Other benefits of drainage include increased yields and easier access and improved suitability for use of farm machinery.

FIGURE [illegible]

Trends in irrigation, by province, 1970–88



Source: Statistics Canada, 1971 Census of Agriculture; Shady (1989).

TABLE [illegible]

Estimated areas drained and still in need of drainage for agricultural purposes

Province	Area drained[a] (ha, 000s)	Area still needing drainage[a] (ha, 000s)
British Columbia	92	600
Alberta	550	1 000
Saskatchewan	3 000	2 000
Manitoba	2 000	2 000
Ontario	1 600	1 600
Quebec	600	850
New Brunswick	13	52
Nova Scotia	17	50
Prince Edward Island	1	30
Newfoundland	1	4
Canada	**7 874**	**8 186**

[a] Including surface and subsurface drained areas.

Source: Shady (1989).

However, drainage to enhance agricultural productivity can also have negative effects. Increased drainage may accelerate the rate at which agricultural chemicals enter the downstream watershed, diminishing water quality and contributing to the eutrophication or premature aging of streams and lakes. Canalization of drainage channels may also drain marshes, swamps, and ponds, eliminating or altering wildlife habitat. In Ontario, conversion of wetlands to productive farmland has been the principal factor in the loss of waterfowl habitat (Girt 1990). Regional studies estimate that 68% of southern Ontario wetlands (south of the Canadian Shield) and 71% of prairie wetlands have been lost, largely to agricultural drainage (Environment Canada 1986; Snell 1987; Clarke *et al.* 1989).

In response to growing concern over the environmental drawbacks of drainage, many jurisdictions are reviewing their procedures to ensure that drainage will be used where it can bring the greatest benefits to agricultural production at the least cost to the environment. This approach will require more attention to the ecological benefits of wetland habitats and a more comprehensive analysis of the costs and benefits of drainage, especially when public funds or subsidies are involved. In some provinces, wetlands have been rated according to ecological and habitat values, and wetland protection policies have been established.

Dryland salinization

The salinization of dryland soils is primarily a natural process, most often found in areas of western Canada that are affected by major regional groundwater systems. Solonetzic or alkali soils have developed in areas where subsoils have high concentrations of sodium salts and water tables are shallow, and they cover an area of 6–8 million hectares in western Canada. They have generally been in existence since long before settlement and cultivation.

Induced, or secondary, salinity occurs when salts become concentrated at or near the soil surface as a result of recent alterations to shallow groundwater conditions that accelerate surface evaporation. These alterations can result from human activities, such as the replacement of natural vegetation with short-season cereal grains and the use of summerfallow.

Salts degrade the quality of water for domestic use, livestock, and irrigation. In areas with saline soils, water quality can be impaired if salts move from the soil to streams, lakes, or groundwater aquifers. Salt water from the drainage of saline soils can degrade the quality of neighbouring, downslope areas. Water quality specialists are now monitoring reclamation of saline areas to determine the need for controls on drainage.

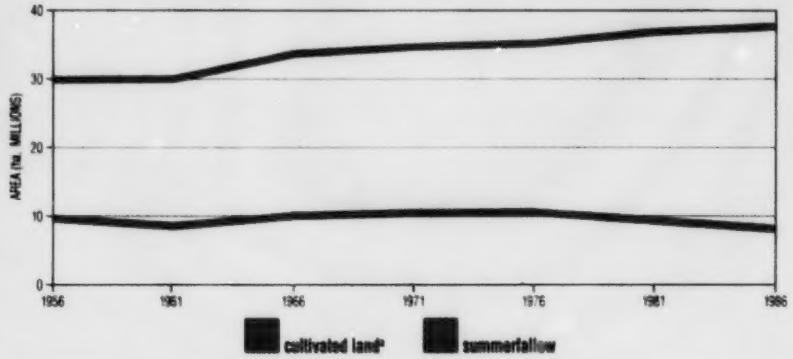
Estimates indicate that approximately 2.2 million hectares or some 6% of improved land in the prairies may be affected by secondary salinity (Dumanski *et al.* 1986). Research is being conducted to determine the rate at which soils are being salinized. The areas affected include southern and central regions of Alberta and Saskatchewan and scattered areas of Manitoba. Current estimates of the loss attributable to salinity range from $104 million to $257 million per year.

Summerfallow

The practice of summerfallow was developed in the prairies as a means of offsetting the effects of drought, one of the biggest constraints on agricultural production in this region. Land in summerfallow is kept bare to control weeds, reduce evapotranspiration, and conserve moisture. The practice also contributes nutrients to the following year's crop by encouraging the oxidation of organic matter and the mineralization of the nutrients it contains.

FIGURE 9.13

Trends in summerfallow compared with cultivated land in the Prairie provinces, 1956–86



[a] Cultivated land = area under crops, improved pasture, and summerfallow.

Source: Statistics Canada, 1956–86 Census of Agriculture.

Leaving soil bare, however, accelerates soil erosion and eventually depresses biological activity because of the loss of organic matter and live vegetation. Furthermore, the practice of summerfallowing may increase soil salinity.

Almost all summerfallow in Canada (98%) is found in Saskatchewan, Alberta, and Manitoba. In 1986, some 8.3 million hectares of prairie farmland were in summerfallow, down 22% from its peak use in the 1970s (Fig. 9.13). Furthermore, the percentage of prairie farms reporting summerfallow has not kept pace with the growth of cultivated land. In 1956, for example, nearly one cultivated field in three was in summerfallow. By 1986, this had declined to almost one field in five.

This overall pattern of decline is due to the realization that, outside of the very dry areas, there is sufficient soil moisture for crops in most years, and that the economic advantage of a crop each year outweighs the small benefit of enhanced soil moisture accrued by frequently leaving the soil without a crop. In addition, there are advantages from a soil degradation perspective. With more fields bearing vegetated cover, the overall risk of wind and water erosion significantly declines.

In the drier portions of the prairies, some types of fallowing are necessary to conserve enough moisture to ensure a crop. In some of these areas, the rate of summerfallow is being maintained. Where the risk of drought is high and where yields are low without irrigation, summerfallow makes the difference between having and not having a crop in some years. In the long term, the increased erosion and threat to soil sustainability raise questions of whether these lands should be cultivated with current techniques. Other methods of conserving moisture can also be used, and the practice of leaving the soil uncovered should generally be avoided.

Conservation practices and mitigation strategies

When cultivated soils are inadequately protected by crop cover or crop residues, they become vulnerable to degradation. The risk is amplified in areas with long slopes and on compacted or impermeable soils. Poor management practices such as monoculture, tilling up and down slopes, and fall plowing worsen the problem. Suitable crop residue cover or a winter cover crop is needed to slow runoff and protect the soil surface. Conservation tillage systems are designed to provide a soil surface with at least 30% crop residue cover to resist erosion. Zero tillage (no-till) represents an extreme example of a reduced tillage strategy (see Box 9.1). Crop residue surveys on the prairies have shown that a combination of low yields and intensive tillage practices, particularly on fallow fields, has left inadequate residue cover to prevent erosion on more than 95% of fallow fields and on 17–30% of cropped fields.

Current estimates of conservation tillage in the prairies indicate approximately 1–5% of the cropped area under no-till with an additional 15–20% under other conservation tillage systems (Olsen 1988). A reduction in summerfallow on the prairies since the 1960s is an encouraging sign of the successful implementation of conservation promotion programs.

In southwestern Ontario, a survey indicated that about 20% of farmers had changed their tillage practices between 1981 and 1986 (Coleman and Roberts 1987). Their main goal was to reduce soil erosion. Provincial programs in this region have encouraged the use of conservation tillage and crop rotations and the planting of permanent cover on highly erodible slopes.

Terracing is the most common structural erosion control practice used in the Maritime provinces. It entails construction of a series of channels across a slope to reduce slope lengths and to intercept and conduct surface runoff into grassed waterways. During 1968–88, some 4 400 ha of land in New Brunswick's potato belt received protection from these erosion control structures (J.L. Daigle, New Brunswick Department of Agriculture, personal communication). Innovative potato farmers in the Maritimes have cooperated closely with government to improve erosion control and soil conservation. Agronomic erosion control measures include crop rotations and green manure crops, winter cover crops, contouring, strip cropping, and conservation tillage. Grain and forage crops are encouraged in rotations, and potatoes are now grown only once every two or three years.

The addition of organic matter to the soil in the form of manure increases biological activity, soil aggregation, and water-holding capacity, enhances soil structure and hydraulic conductivity, and may reduce runoff and soil erosion. Excessive use of manure, however, can be environmentally hazardous.

To till or not to till?

For thousands of years, most agriculture has been based on a fundamental assumption: to grow a crop, the farmer must first till the soil. The evolution of farm technology from the hand-held mattock of our ancestors to the diesel-powered tillage equipment of today reflects a search for ever more efficient means of disturbing the top few centimetres of the earth's crust.

Despite widespread use, conventional tillage (i.e., ploughing and harrowing to prepare a seedbed, cultivation for weed control, and ploughing under of crop residues) has drawbacks. It requires large inputs of time, capital, and energy, it leaves soils vulnerable to damage by erosion and compaction, and it can accelerate the depletion of soil nutrients and the loss of organic matter. In the interests of better soil conservation, researchers have been working to devise strategic alternatives that are described collectively as conservation tillage methods.

Reduced tillage, as the term suggests, is a system in which fewer tillage operations take place in the course of the crop year. It aims to decrease erosion by leaving more crop residue on the soil surface, to conserve soil moisture by reducing evaporation, and to save labour and fuel costs.

Minimum tillage employs still fewer tillage operations and generally includes the application of herbicides to control weeds that are not being destroyed by cultivation.

Zero-tillage involves seeding or planting a crop directly into untilled soil through the crop residue or stubble, using special seed drills and planters that cut through residues. Residues from the harvest are spread on the field and build up a layer of crop residue. In dry areas such as the prairies, this residue will trap snow in winter and act as a summer mulch to retain moisture. Herbicides often play a major role in weed control with this system. Often no more herbicide is used than with conventional tillage.

As with most departures from tradition, conservation tillage is still a matter for debate among some farmers. The choice of method may vary considerably, depending on the soil and climatic conditions that exist in a given region of the country. Generally, however, the use of conservation tillage methods to replace the conventional tillage cycle results in significant benefits, including:

- reduced soil erosion
- improved soil moisture content
- increased soil organic matter
- decreased requirements for labour and energy.

Programs and strategies

The problems of land degradation and environmental quality noted in the foregoing pages have not proceeded unnoticed or unchecked. Despite economic pressures to achieve maximum productivity, farmers tend to be very conscious of the long-range importance of exercising good stewardship over their land and to welcome policies and programs aimed at conserving agricultural resources.

Soil and water surveys and monitoring

Information concerning trends in soil and water quality is gathered through a variety of survey programs that are generally undertaken through federal–provincial cooperative agreements. Canada currently spends about $6 million yearly on ongoing survey programs and special studies under Federal–Provincial Economic and Regional Development Agreements (ERDAs), whereas the provinces contribute about $4 million annually.

The long-term monitoring of the nature and rate of change of soil degradation problems is being addressed through the Soil Quality Evaluation Program of the National Soil Conservation Program. The Soil Quality Evaluation Program is Agriculture Canada's response to the critical need for a monitoring system to determine soil quality from a national perspective and to assess how soils respond to environmental influences and land-use practices. The intent is to provide periodic reports on the "state of the soil."

An inventory of on-farm water resources is part of the soil survey procedure and includes measurements of water table levels, soil drainage classes, the amount of water available to plants, salinity level, and suitability of irrigation. Other studies measure the quality of groundwater and drainage water.

Soil and water services

The provision of soil and water services to farmers is primarily the responsibility of provincial governments. Provincial agricultural extension services are involved in soil and water conservation, as well as soil management for enhanced productivity. In the Prairie provinces, the federal government also provides technical and financial assistance, through the Prairie Farm Rehabilitation Administration.

Ontario has been seriously committed to soil conservation under the Ontario Soil Conservation and Environmental

Protection Assistance Program and the Land Stewardship Program. Provincial soil conservation specialists have also been involved with the "Tillage 2000" research and demonstration program, aimed at technology development and transfer for conservation tillage, and with Food Systems 2002, a program intended to reduce pesticide use by 50% by the year 2002. In the Lake Erie basin, the Soil and Water Environmental Enhancement Program is a five-year, $30 million, federal–provincial program to reduce phosphorus movement from agricultural lands to the Great Lakes, in accordance with the Canada–U.S. Great Lakes Water Quality Agreement.

Alberta's extensive on-farm soil and water conservation program has been implemented by soil conservationists of Alberta Agriculture and the Prairie Farm Rehabilitation Administration. Assistance has also been provided through the Canada–Alberta Agreement on Soil, Water and Cropping Research and Technology Transfer.

Quebec has also implemented an important soil conservation program, much of which was integrated with the ERDA. Incentives and assistance provided by Quebec for storage, handling, and proper use of manure (to reduce surface water contamination by manure runoff and to improve soil fertility) have amounted to about $39 million per year, one of the largest contributions to environmental quality improvement related to agriculture in Canada.

New Brunswick has conducted a relatively successful soil conservation program aimed at the potato-growing region, where extensive areas of terraced fields can now be seen. Prince Edward Island is following a similar program. In Saskatchewan and Manitoba, cooperative and comprehensive federal–provincial soil conservation programs were developed from 1984 to 1989 under the Agri-Food Regional Development Subsidiary Agreements to augment existing soil conservation activities.

Except for Quebec and Ontario, the provinces have provided little direct financial and technical assistance to producers to control the quality of runoff water from crop or livestock enterprises. The Prairie Farm Rehabilitation Administration provides some assistance with effluent irrigation projects in the three Prairie provinces.

The National Soil Conservation Program was announced in December 1987. The $75-million federal fund for this program was to be matched by the provinces, for a total of $150 million over three years, and distributed among the provinces in proportion to the degree of soil degradation and the provincial willingness to share costs. The program provided on-farm technical and financial assistance for soil conservation practices, demonstrations, research, monitoring, and public awareness. The National Soil Conservation Program is an important part of the national agriculture strategy adopted by First Ministers in November 1986. While the program follows its course, a federal–provincial committee on environmental sustainability, established in 1989, developed an action plan to address not only soil and water problems but all issues pertaining to environmental sustainability, including wildlife habitat, genetic resources, air and climate, and waste management. Many aspects of this plan will be addressed in the implementation of the sustainable agriculture component of the federal government's Green Plan during 1991–97 (Government of Canada 1990).

Following the signing of the 1987 Protocol to the Great Lakes Water Quality Agreement between Canada and the United States, a five-year, $125-million program for improving Great Lakes water quality was announced in October 1987. This program emphasizes restoration and preservation programs as well as initiatives to prevent pollution by toxic chemicals, including those arising from agricultural activities. It also promotes measures to contain and control contamination in sediments, groundwater, runoff, and atmospheric deposition.

On another front, the North American Waterfowl Management Plan, signed in 1986 (U.S. Department of the Interior and Environment Canada 1986), aims to improve waterfowl habitat in 34 designated areas across Canada, representing 2.2 million hectares of marginal agricultural lands, in order to restore waterfowl populations to the mid-1970s level. Funded by public and private sources in both Canada and the United States, this program will invest more than $1 billion to secure and enhance wetland habitat over a period of 15 years. Included among its strategies are agreements with farmers to conserve or improve their wetland holdings.

Some concerns have been expressed that the safety nets of the agricultural sector could act as disincentives to conserve land for other uses. For example, some crop insurance programs that guarantee a minimum return on planted land have been thought to slow down the pace of marginal land being returned to grassland through conservation-oriented programs, such as Prairie Care and North American Waterfowl Management Plan agreements. Farmers might even wish to withdraw land from existing permanent cover programs. Newly instituted environmental reviews of federal or federal–provincial crop insurance and subsidy programs will help reduce the conflicts between agricultural programs and environmental concerns. Ducks Unlimited and other conservation organizations are currently assessing the impacts of safety net programs on their own initiatives.

Conservation awareness

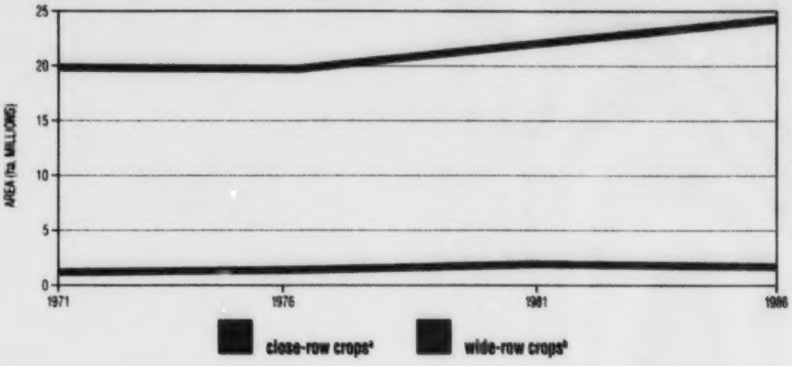
Both levels of government have a responsibility to promote public awareness of soil and water resource degradation. The National Soil Conservation Program, the Soil and Water Environmental Enhancement Program, and the Great Lakes Water Quality Initiatives Program all include public information components. Provincial extension services focus on information and technology transfer to farmers, and many actively promote soil conservation awareness among the general public. Soil Conservation Canada, a nonprofit organization of farmers and specialists from industry, government, and education, also promotes public awareness of soil conservation issues. Such activities have been supported by a wide range of farm and environmental groups. More recently, conservation awareness has been identified as an important issue in all areas of environmental sustainability (Agriculture Canada 1990).

Crop production

Crop production practices can have negative, neutral, or positive effects on the environment. Wide-row crops such as corn, potatoes, and certain vegetables have often been associated with soil degradation. The soil, left bare between the rows, is very prone to erosion by water. Corn production has been associated with soil compaction. Although the total area devoted to corn production is increasing, environmentally sound cultural practices such as crop rotation, conservation tillage, inter-row seeding to legumes, and strip cropping are now widely used. On the other hand, close-row crops (e.g., cereals, canola, flaxseed) are less frequently linked to environmental problems than wide-row crops. Figure 9.14 shows trends in selected cropping practices over a 15-year period. The total area of major close-row crops increased about 20% between 1971 and 1986.

FIGURE 9.14

Trends in cropping practices in Canada, 1971–86



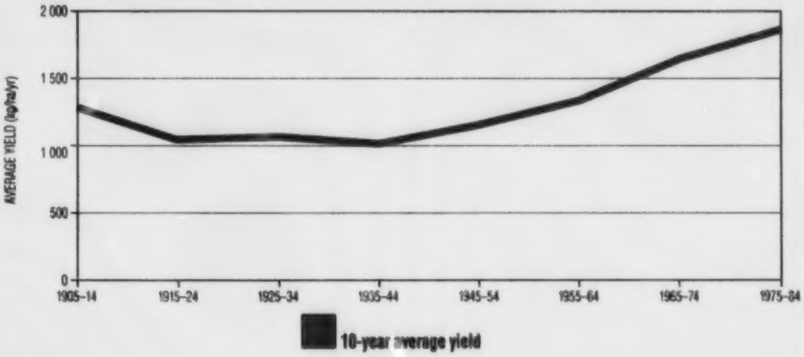
[a] Wheat, oats, barley, canola, and flaxseed.

[b] Corn, potatoes, vegetables, peas, and beans.

Source: Statistics Canada, 1971–86 Census of Agriculture.

FIGURE 9.15

Trend in wheat yields in the Prairie provinces, 1905–84



Source: Hedlin (1986).

Fertilizers

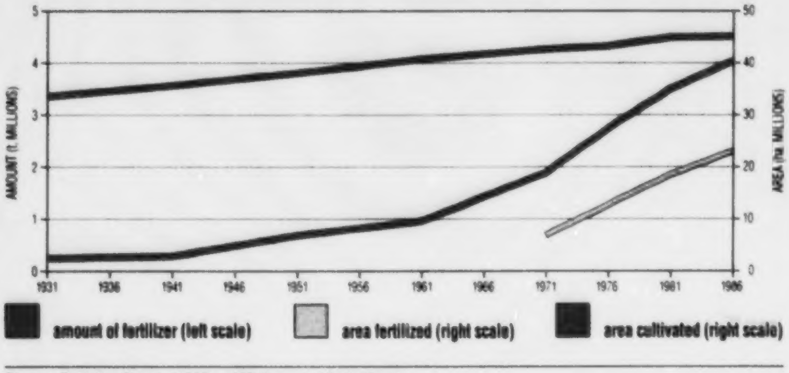
Today, most cultivated crops receive the nutrients they need from the air, from the water, and through a soil fertility program that may include legumes in the sequence of crop rotations, as well as the application of chemical fertilizers and/or manures. The primary or major elements supplied by soils and fertilizers are nitrogen (N), phosphorus (P), and potassium (K). A great deal of knowledge is available regarding the use and benefits of these elements. Other elements, however, are also necessary for plant growth; they include secondary elements (calcium, magnesium, sulphur) and micronutrients (e.g., iron, manganese, boron). Less is known about these micronutrients. This has tended to result in an inefficient approach to their use and application in fertilizers.

When pioneer farmers first cultivated the prairie soils for crop production, they obtained high yields from soils that were rich in native organic matter. Cultivation reduced the natural reserves of soil nutrients, and after 20 or 30 years the need to replace depleted nitrogen and phosphorus was evident as yields began to decline. Figure 9.15 illustrates how wheat yields fell from the early days of cultivation until the end of World War II. Since then, yields have increased in step with the increasing use of fertilizers and new crop varieties.

Since the 1930s, the use of commercial fertilizers on Canadian croplands has increased in both tonnage and area fertilized. In 1930, about 250 000 t of fertilizer were applied throughout Canada. The use of fertilizer approached 1 million tonnes by 1960 and quadru-

FIGURE 9.16

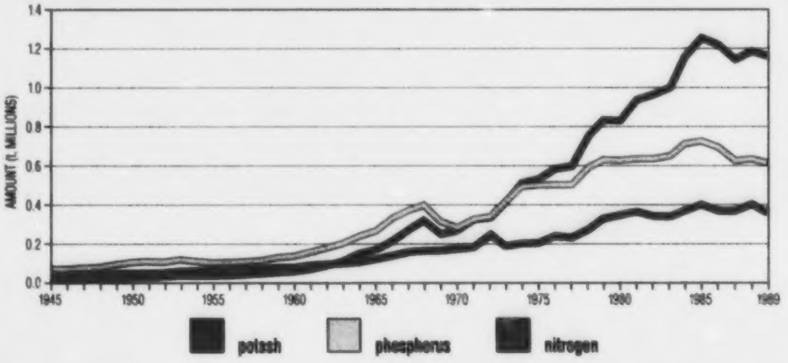
Fertilizer use compared with cultivated area in Canada, 1931–86



Source: Statistics Canada (1986a, 1986 Census of Agriculture).

FIGURE 9.17

Nutrient content of fertilizers sold, 1945–89



Source: Statistics Canada, 1945–89 Fertilizer Trade, Catalogue 47-207, various issues, and Agriculture Canada, Farm Policy Development Branch.

TABLE 9.4

Crop uptake of nitrogen (N) and phosphorus (P) in western Canada and its relationship to fertilizer use

Year	Crop uptake (t, 000s)		Fertilizer used (t, 000s)	
	N	P	N	P
1883–1953 (avg.)	203	36	1	2
1954–64 (avg.)	446	75	22	20
1965–71 (avg.)	623	110	128	59
1972	637	111	126	64
1973	686	118	262	100
1974	545	93	308	133
1975	668	115	346	146
1976	800	136	363	131
1977	781	134	382	121
1978	831	142	530	156
1979	693	118	591	164
1980	733	125	590	169
1981	898	153	652	175
1982	982	166	682	171
1983	898	151	721	180
1984	696	134	854	204
1985	902	153	914	210
1986	1 133	192	896	202
1987	995	169	825	177

Source: Flaten and Hedlin (1988).

pled again to 4 million tonnes as of 1985 (Fig. 9.16). Since 1985, fertilizer use has remained steady (Table 9.4).

A corresponding increase in the area fertilized has also occurred. By 1985, fertilizers were being applied to more than 50% of Canada's cultivated fields compared with 16% in 1970, but practices vary widely from region to region (Statistics Canada 1986*b*). In some regions (e.g., southwestern Ontario, southern Quebec, and southern Manitoba), the proportion of land receiving fertilizer now surpasses 75%; in southeastern Alberta and southwestern Saskatchewan, on the other hand, less than 30% of improved land is fertilized.

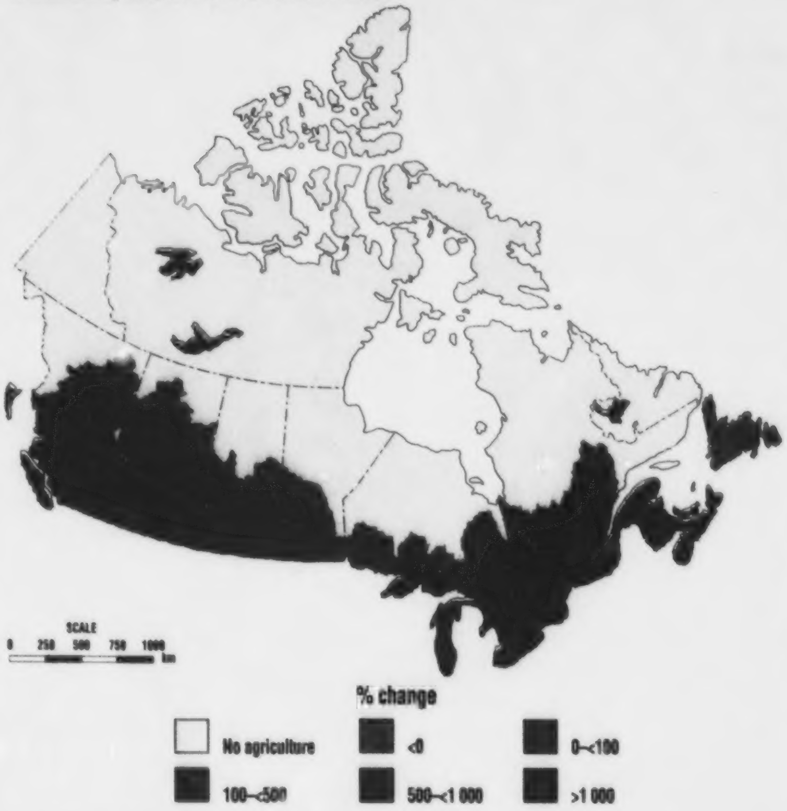
Statistics on fertilizer use underrepresent the growth in nutrients applied to crops, because they do not reflect the steady increase of nutrient content of fertilizers (Fig. 9.17). For example, nitrogen, which amounted to about 10% of the total fertilizer mixture in 1960, reached about 30% in 1985. Potassium and phosphorus components have risen as well.

Figure 9.18 illustrates the increase in fertilizer nutrients from 1970 to 1986. Increased inputs are required to sustain the soil's ability to support increased yields. However, it should be noted that in some areas, such as southwestern Ontario, applications of fertilizer were already high prior to 1970, and they have increased relatively little since. The greatest percent increases are in the prairies, where the quantity of fertilizer applied was relatively small 20 years ago compared with that in the rest of Canada. The increase compensated for declining soil fertility and supported higher-yielding crops.

In the formerly forested soils of central and eastern Canada, native organic matter was never as important a source of nutrients for crop production as it was in the prairies. Figure 9.19 illustrates the dramatic yield increases obtained from corn in Ontario since

[illegible]

Percent change in application of nutrients in the form of fertilizer, by subbasin, between 1970 and 1985



Note: Nutrients in 1970 were derived from fertilizer expense data.

Source: Statistics Canada, Environment and Wealth Accounts Division and the Agriculture Division.

the 1920s. These increases reflect the development of better varieties and hybrids and were made possible by increased fertilizer applications that kept pace with the production potential of the plants. Similar increases in fertilizer demand have accompanied the development of new, more productive varieties of many other crop plants as well.

Improved crop varieties increase production, which requires a greater uptake of nutrients; as more nutrients are exported from the soil with each harvest, greater quantities of fertilizer must be applied to replace them. Table 9.4 shows that the removal and export of nitrogen from the prairies in crop production continue to exceed the replacement of this nutrient by fertilizers. Continuing mineralization of nitrogen from organic matter as well as nitrogen fixation by leguminous plants grown in crop rotations explain this discrepancy. Phosphorus, on the other hand, is used at a slightly higher rate than that at which it is being exported. This is partly a reflection of the capacity of prairie soils to immobilize fertilizer phosphorus and reduce its availability to plant roots. It may also reflect a need to restore some of the depleted phosphorus levels in soils that had not previously received adequate amounts of fertilizer.

Although fertilizer use is essential to maintain crop yields, the spiral of rising costs demands that greater emphasis be placed on efficient application. Fluctuations in weather, timing, lack of prior soil testing, and inherent soil properties can all diminish the effectiveness of applications. Taking these factors into consideration and using the best available technology in fertilizer application will reduce costs and environmental problems.

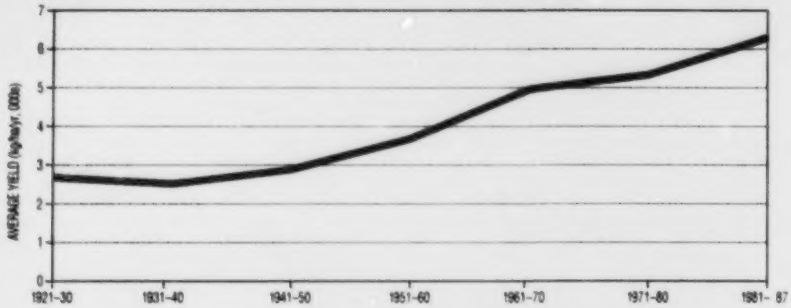
When fertilizer is not used by crops, environmental problems such as nitrate contamination of surface water and groundwater and phosphorus runoff to surface waters may follow. Nitrate originating from the mineralization of organic matter may also lead to water contamination if not taken up by a cover crop.

Once in the water supply, nitrogen can create health problems for humans and other animals. When the nitrogen in drinking water (as nitrate and nitrite) exceeds the recommended level of 10 mg/L, there is a risk it may interfere with oxygen transport within the body. Children under one year in age, cattle, and young animals are most susceptible. Most of the isolated cases of nitrate pollution of water supplies in Canada have been traced to farm wells with faulty casings located close to manure storage areas. Nevertheless, reduction of nitrogen losses from fields to groundwater supplies must be a priority if a wider problem is not to develop.

If fertilizer is not worked into the soil, the phosphorus tends to move off the field with runoff, attached to soil particles or dissolved in water. This loss is greatest in fields close to streams and in fine-textured soils. Phosphorus does not appear to be toxic even at the high concentrations sometimes found in open waters. However, only a small quantity is required to stimulate the growth of algae and other aquatic

FIGURE 9.19

Corn yields in Ontario by 10-year periods, 1921–87



Source: Agricultural Statistics for Ontario.

TABLE 9.5

Cost of pesticides by farm type, 1986[a]

Farm type	No. of farms	Total cost ($, millions)	Average cost per farm ($)	Total area (ha, 000s)	Cost per hectare ($)
Dairy	22 482	35.0	1 557	1 876	18.66
Cattle	27 362	52.1	1 905	3 368	15.47
Hog	7 718	28.7	3 716	865	33.18
Poultry	1 729	5.9	3 415	129	45.74
Wheat	42 488	177.7	4 182	9 748	18.22
Small grain	51 802	277.8	5 363	10 711	25.94
Other field crop	4 572	36.9	8 076	454	81.28
Fruit	6 708	20.5	3 056	83	246.99
Vegetable	3 558	17.2	4 854	134	128.36
Specialty	4 950	10.9	2 203	91	119.78
Livestock combination	4 121	17.7	4 307	833	21.25
Other types	5 010	13.8	2 756	469	29.42
Mixed farms	9 131	31.6	3 456	1 301	24.29
Total (all farm types)	**191 631**	**725.8**	**—**	**30 071**	**—**
Average (all farm types)	**—**	**55.8**	**3 757**	**—**	**62.20**

[a] Information based on farms generating 50% or more of farm revenue from sales of a particular commodity.

Source: Clutton (1989).

organisms, leading to an array of problems associated with the eutrophication of lakes and streams.

The majority of fertilizers added to the soil are derived, directly or indirectly, from nonrenewable natural resources. Phosphorus and potash are mined, and natural gas is required in the production of nitrogen fertilizer. The supply of these resources is finite, and in fact all phosphate rock used in Canada is currently imported. Better methods are needed to recycle plant nutrients from sewage sludge, wastewater, and other organic wastes back to the land. Regrettably, many of these waste streams are contaminated by household and industrial chemicals, and it is questionable whether their application to the land is either environmentally or economically acceptable.

Pest control

Weeds, diseases, and insect pests have historically accounted for significant losses in yield across Canada. The use of pesticides to control these problems has produced economic benefits in the form of increased yields and improved product quality. Dependence on the increasing use of synthetic agricultural pesticides to achieve these goals has raised concerns (McEwen and Stephenson 1979). Pesticide use can have environmental side effects such as pollution, toxicity to nontarget species, and soil contamination — costs that are rarely considered in the analysis of economic benefits.

Ideally, the production of crops with inherent genetic resistance to disease and insect damage would be the ultimate defence against pest and disease problems. Once such varieties were established, no additional costs would be incurred, and environmental impacts would be minimal. Some progress has been made in this direction. An example is found in cereals, where stem rust resistance has been introduced in spring wheat varieties. Unfortunately, such examples are very limited, and agricultural production will have to continue to rely on chemical and biological methods of pest control to maintain quality and productivity.

Chemical control

The use of pesticides — the term refers generally to insecticides, fungicides, and herbicides — has grown dramatically in Canada in recent years. The distribution of major changes in chemical pesticide use across Canada is shown in Figures 9.20 and 9.21.

In 1970, about 8.6 million hectares, or 20% of all cultivated land, were sprayed with herbicides to control weeds and brush (Statistics Canada 1986*b*). By 1985, that figure had more than doubled to 22.9 million hectares, or about 51% of all cultivated land, with the greatest intensity being in southern Ontario and southern Manitoba.

Although less widespread, the application of pesticides to control insects and disease has increased at an even faster rate. In 1970, 2% of cultivated land was sprayed for insects; in 1985, this had grown to over 10%, or 4.6 million hectares. In 1985, the highest concentrations of insecticide spraying occurred in southern Saskatchewan, Prince Edward Island, the upper Saint John River valley in New Brunswick, and selected parts of southern Ontario and Alberta. Statistics for insecticide use in 1985 are higher than average for the southern prairies, owing to control measures taken to combat a major outbreak of grasshoppers during that growing season.

Pesticides are not applied equally among all farm types. By far the most frequent applications are found among fruit, vegetable, and specialty farms (Table 9.5). In contrast, wheat and grain farms apply relatively low amounts of pesticides but over larger areas.

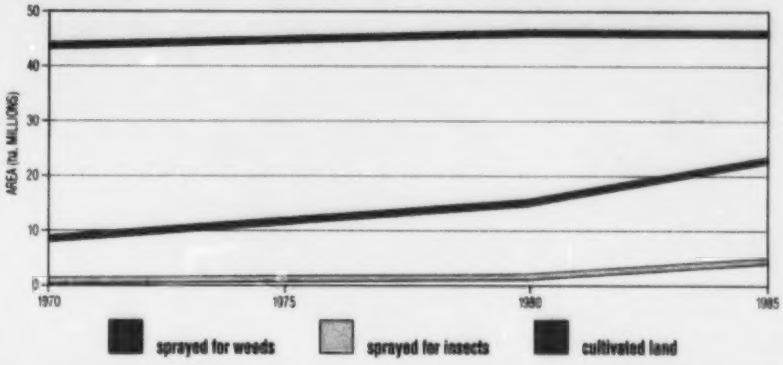
The degree to which a particular pesticide poses an environmental risk is determined by several factors:

- frequency of use
- rate of application
- persistence in toxic form in the environment
- mobility, or retention by soil particles, solubility in water, and volatility in air
- concentration in living organisms (bioaccumulation)
- toxicity to nontarget species.

Based on analysis of these factors, some pesticides have been removed from use in Canada and replaced by others that pose less risk to the environment. Chlorinated organic insecticides, such as aldrin and dieldrin, were nonspecific and persistent. They were once widely employed to control insects in agricultural, domestic, forestry, and industrial

FIGURE 9.20

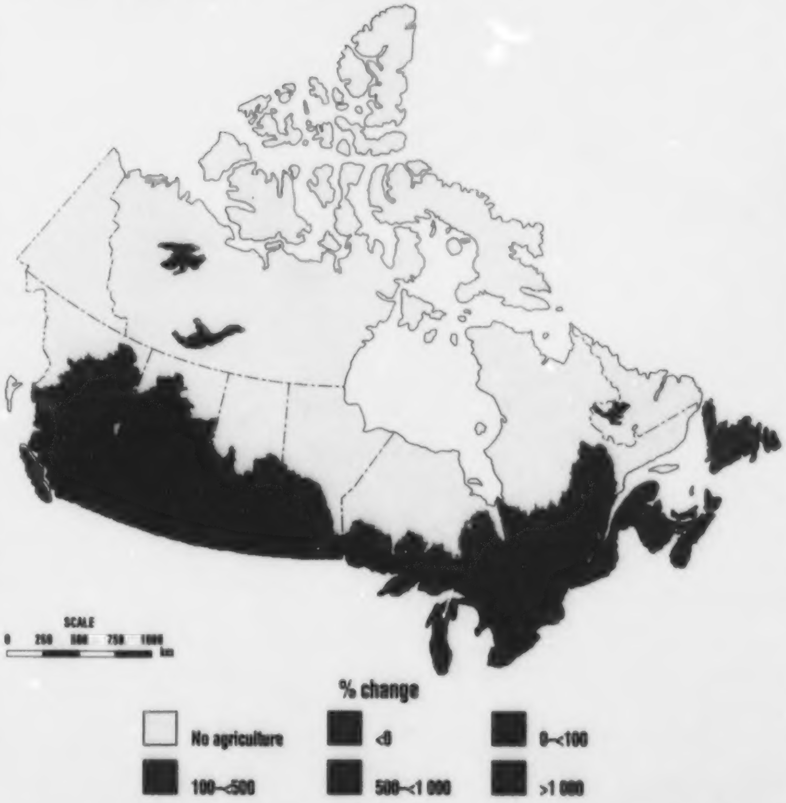
Area sprayed for weeds and insects, 1970, 1980, and 1985



Source: Statistics Canada (1986*a*, 1986 Census of Agriculture).

FIGURE 9.21

Percent change in amount spent on agricultural pesticides, by subbasin, between 1970 and 1985



Note: Percent change calculations were performed on constant dollar values. Some of the shaded subbasins have very little agricultural activity.

Source: Statistics Canada, Environment and Wealth Accounts Division and Agriculture Division.

situations, but their use in Canada was discontinued some years ago. More recently the herbicide alachlor, a compound linked to potential health-related effects, was also removed from use in Canada. At present, pesticides must pass rigorous testing before they can be registered for use.

The presence of pesticides in surface water, groundwater, and sediments is of particular concern. Atrazine, a herbicide widely used in corn production, is frequently found in surface waters in the Great Lakes basin; aldicarb, an insecticide used on potatoes, has been detected in groundwater in some potato-growing areas; and the herbicide metolachlor, used in corn and soybean production, is sometimes transported to streams with eroded sediments. Research and monitoring programs are attempting to track these and a wide range of other pesticides and to determine their breakdown and migration in soils and plants. Further restrictions will likely be imposed on the use of any that appear to present environmental problems.

New classes of pesticides requiring very low application rates, such as synthetic pyrethroid insecticides and sulfonylurea herbicides, continue to be developed and tested (Schwinn 1988). The fact that they are effective in low dosages has introduced a new dimension of precision and accuracy to modern pesticide technology. The demand for precision spraying, coupled with research on how to reduce application rates and losses to off-target drift, has led to the development of innovative pesticide delivery systems.

The development and use of more selective, less persistent, and less mobile pesticides are important continuing trends. These pesticides have little or no potential for impact on nontarget wildlife species or water resources. The *Pest Control Products Act and Regulations*, administered by Agriculture Canada, ensures the safety, merit, and value of pesticides in Canada. The regulations focus attention specifically on human health, environmental protection, and pesticide performance. Carefully controlled procedures for use and disposal will help to reduce pesticide use and minimize the contamination of air, soil, and water. A pilot program for the collection, rinsing, shredding, crushing, and delivery of empty pesticide containers to recyclers or approved disposal sites has been undertaken jointly by the pesticides industry and the provinces of Alberta, Saskatchewan, and Manitoba. Similar projects in other provinces are being planned. Research into new application techniques to maximize deposition on the target, reduce pesticide inputs, and eliminate drift is being funded by federal and provincial agencies. The Food Systems 2002 program, for example, aims to cut pesticide use in Ontario by 50% by the year 2002 (see Box 9.2).

BOX 9.2

Food Systems 2002

A 50% reduction in the agricultural use of pesticides by the year 2002: that is the goal of Food Systems 2002, a comprehensive program introduced in 1988 by the Ontario Ministry of Agriculture and Food.

Contamination of water and food was one of the principal concerns that led to adoption of the ambitious undertaking. Others included increased resistance of pests to the available array of poisons and a slowdown in the development of new pesticides for use against the resistant strains.

The new initiative will extend programs of integrated pest management and the Ontario Pesticide Education Program that have been operating in Ontario since 1966. The strategy combines biological and cultural methods of minimizing the vulnerability of crops to pest damage with selective use of "narrow-spectrum" pesticides that will kill specific pests without doing any harm to beneficial organisms.

Over a 15-year span of operation, Food Systems 2002 will promote research into the development and implementation of nonchemical pest control methods, backed up with on-farm education to inform farmers of new methods and with field teams of pest management specialists to help farmers adopt the new pest control technology. Biotechnology will play an important part in the program, through the development of pest-resistant crop varieties.

Currently, a savings on chemical costs amounting to more than $100 million a year is forecast by the provincial ministry.

Biological control

Biological control involves the use of predators, parasites, and pathogens (i.e., natural enemies) to control weeds, insects, and disease. Classical biological control involves the importation and release of exotic natural enemies, and there are several examples of the successful use of this method in Canada (Kelleher and Hulme 1984).

The use of beneficial insects that are parasites and/or predators of the target species is one way to gain biological control of pest organisms. To work effectively it requires a detailed understanding of the ecosystem into which the control species is being introduced. An example now nearing successful completion is the use of insects to control the pasture and rangeland pest known as knapweed. Diffuse and spotted knapweed (*Centaurea diffusa* and *C. maculosa*) are herbaceous weeds of the dry grassland. They occur in British Columbia, where a herbicide program to contain them costs the province about $1 million per year. Spreading eastwards, the two weed species could dominate 10 million hectares in western Canada and a much larger area in several states south of the border. Canadian biological control programs have reduced seed production by about 90%. It appears that on Kentucky bluegrass ranges, the knapweed can now be managed by restricting grazing to grass growth periods. Current introductions of root-feeding insects and planned introductions of additional seed-head insects will make knapweed management easier and extend control to other grassland associations.

Biological control by pathogens such as bacteria, viruses, and nematodes is also being pursued with varying degrees of success. *Bacillus thuringiensis*, or B.t., is a naturally occurring bacterium that is pathogenic to several groups of insects. It is widely used in agriculture and forestry against insects such as the spruce budworm (Hadfield 1988) and against moths and butterflies on cole crops such as cabbage, broccoli, and brussels sprouts (Barrett and Witt 1987).

Progress has also been made in the field of biological herbicides. The indigenous fungus *Colletotrichum gloeosporioides* f. sp. *malvae* (C.g.m., for short), registered in 1988 under the tradename BioMal, is currently being used for the control of round-leaved mallow (Mortensen 1988).

With proper selection criteria, a biological control agent can be very specific in its host range, and nontarget plants and insects will not be attacked. In addition, if properly selected, biocontrol agents leave little environmental residue following their application and are generally less hazardous than their chemical counterparts (Brown *et al.* 1987).

There are possible constraints to the use of biological controls. Target pests may develop resistance to, or tolerance of, the control agent. Furthermore, certain agents, such as viruses, are difficult to produce in large quantities (Jutsum 1988). A biological control agent that is not native but imported from another area may create new problems because controls on its own population may be lacking in the ecosystem to which it is introduced. Although such controls are generally perceived to be preferable to chemicals, there is still some concern regarding their safety. Such concerns may well increase with the use of biological control organisms.

Integrated pest management

The term "integrated pest management" (IPM) has become synonymous with the concept of environmentally sound pest control procedures for sustained agricultural production. IPM combines chemical, biological, cultural, and genetic methods to maximize effective and economical pest control, while minimizing harmful effects on nontarget organisms and the environment. It requires intensive monitoring of pest populations to ensure optimum results (Vereijken 1989).

Historically, orchard insect pests have been major targets for IPM in Canada and the subjects of pioneering work in the Annapolis Valley, Nova Scotia. However, by 1979, IPM programs covered insect pests of forages, cereals, oilseeds, orchards, vegetables (including potatoes), tobacco, greenhouse produce, animals, and stored products. With some change in emphasis, these programs are still in place today. They are provided to growers on a fee per hectare basis and have reduced insecticide use by up to 90% in monitored fields.

Over the past 10 years, advances have been made in many areas of IPM, including the development of better monitoring techniques (e.g., use of pheromones[1] and traps) and improved understanding of pesticide resistance. The availability of mass rearing techniques and facilities as well as public concerns about pesticide use have led farmers in British Columbia, for example, to accept a sterile codling moth program developed between 1972 and 1978 at Agriculture Canada's Summerland Research Station.

Although IPM has resulted in a decrease in pesticide use in some cases, pesticides continue to be used within IPM systems. The implementation of IPM programs has not been easy for a variety of reasons (Stoner *et al.* 1986; Wearing 1988). Farmers often resist change unless economic returns can be assured. After the capital outlay for spray equipment and chemicals has been made, traditional pesticide strategies are attractively simple. By comparison, IPM is relatively complex, is far more labour-intensive, and requires a large number of trained personnel and a high degree of cooperation amongst the growers. In case of failure, farmers face much greater financial risks under IPM.

Biotechnology

Through genetic modification, tissue culture, embryo manipulation, and a host of other methods, biotechnology holds the promise of modifying the genetic components of crops far more quickly than classical breeding techniques could ever do. For this reason, it offers exciting possibilities for improved crop management. Increasing plant resistance to pests is one area where biotechnology can help (Martens 1987). Several strategies have already been developed to introduce genes for heightened resistance into plants. One such example is the introduction of the genes for producing the insecticidal toxin of B.t. into a plant (Fischoff *et al.* 1987).

The development of nitrogen-fixing *Rhizobium* bacteria as a commercial product is an example of how living organisms may be used to reduce the need for chemicals — in this case, nitrogen fertilizer. However, because *Rhizobium* strains differ in their effectiveness at fixing nitrogen and in competing with other soil microorganisms (Rennie and Dubetz 1986), a great deal of research will be needed to maximize the benefits of these organisms.

Another group of soil organisms that aid in plant nutrient absorption are those that can render phosphate nutrients more soluble. This diverse group includes bacteria, including actinomycetes, and fungi. Biotechnology offers the potential to transfer the microorganisms' genetic ability to dissolve nutrients to the roots of plants themselves, permitting them to utilize surrounding reserves of nutrients more effectively (Kucey *et al.* 1989).

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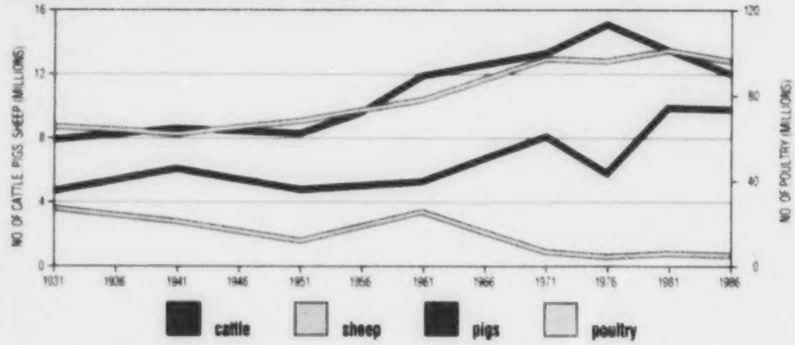
[1] Any substance secreted by an animal that influences the behaviour of other individuals of the same species.

FIGURE 9.22

Trends in livestock in Canada, 1931–86



Source: Statistics Canada (1986a, 1986 Census of Agriculture)

Biotechnology also permits plant geneticists to develop new plant strains with desirable characteristics. For example, quality forage crops can be developed for use on marginal lands so that these lands can be removed from grain and row crop production.

Biotechnology holds out the promise of benefits in animal breeding, too. One is the development of animals with improved resistance to disease and stress. Another, with direct implications for reducing the production of methane (a greenhouse gas) in cattle, is the alteration of rumen and gut microorganisms to achieve increased efficiency of food conversion.

Animal production

Modern intensive methods of animal husbandry can affect environmental quality in a variety of ways, ranging from the degradation of local air quality by offensive odours to more serious problems of pollution in surface water and groundwater as a result of improper manure disposal.

Trends in livestock populations in Canada for 1931–86 appear in Figure 9.22. The number of cattle peaked in the mid-1970s and has since fallen 20%. In contrast, the numbers of pigs has increased about 70% over the same time period. Poultry levels have hovered around 100 million since the 1960s. In addition to these trends, production methods have also changed. Total confinement of dairy cattle, pigs, and poultry is now common practice.

The increases in pigs and poultry, both of which are produced under intensive livestock management conditions, have been associated with environmental problems. Manure storage and disposal, if not properly managed, can result in water contamination by nitrates and in air pollution as a result of ammonia and methane volatilization. Furthermore, soil productivity may be impaired by excessive nutrient accumulation. When limited land is available, manure disposal can become a problem.

Cattle and sheep are often produced under less intensive conditions, except for the feedlot finishing of beef. These commodities generally have a less negative effect, except in the case of feedlot operations where manure handling can present problems similar to those experienced with pigs or poultry.

Manure management

Livestock manure constitutes one of the principal, non-point sources of nutrient pollution in Canada, and one that has yet to be adequately addressed from an environmental perspective. Concentrating a lot of animals on a small area of land poses a waste management challenge with respect to either the disposal or the economic use of manure. The sheer quantity is enormous. Cattle produce 40 kg or more of manure for each kilogram of edible beef that is eventually marketed, and a kilogram of edible pork is associated with 15 kg of manure (N.K. Patni, Agriculture Canada, personal communication). All told, farm animals in Canada generate about 322 million litres of manure every day, with cattle accounting for 85% of the total. Although the volume of manure produced by poultry and swine is small in comparison, their relative impact on the environment may be greater, because swine and poultry are commonly raised in confinement, on a small land area.

About 75% or more of the nitrogen, phosphorus, and potassium in feed is excreted by animals. The equivalent fertilizer value of these nutrients alone is about $900 million, or about 5% of annual farm cash receipts from livestock products. Not all animal waste is efficiently used in land recycling systems for crop production.

The role of animal wastes in improving long-term soil productivity is well recognized. Regrettably, waste management practices that could benefit the environment tend to be economically unattractive in the short term.

Waste management

Inevitably, production of livestock and crops produces wastes as well. In general, crop residues are less of a potential environmental problem than manures. Straw, for example, may be used as bedding and feed for animals. Nevertheless, flax straw is often disposed of by burning, and efforts are now being made to expand the commercial applications for this high-fibre waste product.

Indirectly, agriculture generates solid wastes, such as used packaging from fertilizer and pesticide products. Contamination of surface water and groundwater can also result from runoff of water used to clean farm buildings and equipment.

The food-processing industry generates large amounts of organic wastes, as well as effluents from cleaning and rinsing equipment. Improperly managed, the disposal of solids and wastewater may lead to water contamination and health problems. In addition, concerns have been raised about air quality in the vicinity of processing plants.

Another environmental problem for the agri-food sector is packaging (see Chapter 25). Virtually all food products are sold in disposable packages. Food packaging accounts for about one-third of all packaging material, which comprises a significant portion of the solid waste in municipal landfills (Canadian Council of Ministers of the Environment 1990). The risks such sites pose to surface water and groundwater and to air quality are a major and growing concern. Unnecessary packaging material, which often has a very short life span between use and disposal, also contributes to the depletion of the renewable and nonrenewable natural resources required for their production.

OUTLOOK

In the mid-1980s, it was recognized that the Canadian agri-food sector faced important challenges if Canada's soil and water resources were to be conserved. The challenge continues into the 1990s, as Canadians demand protection of environmental quality for future generations. Farmers, agri-food businesses, and governments are attempting to meet these challenges in a concerted effort to achieve long-term sustainability of agriculture. The Federal–Provincial Agriculture Committee on Environmental Sustainability (Agriculture Canada 1990) offers this definition:

> "Sustainable agri-food systems are those that are economically viable, and meet society's need for safe and nutritious food, while conserving or enhancing Canada's natural resources and the quality of the environment for future generations."

The future direction of agriculture in Canada can be seen in a variety of specific initiatives. For example, applying the principles of sustainability to soil management could require reduction of tillage and summerfallow, increased crop rotation, conservation of crop residues, or maintenance of shelterbelts or wetlands. To make such changes effectively will necessitate research, environmental education, technology transfer, and on-farm training. Land use will have to be monitored closely, and future planning and management must reflect an ecological approach to agriculture.

If the increased cooperation implicit in these plans can be maintained, the environmental consequences should be positive. The restatement of many of these initiatives in Canada's Green Plan underlines the seriousness of the challenges ahead. For sustainable agriculture to work, farmers must be given options that do not threaten the economic viability of their farms yet encourage them to become as good managers of the environment as they are of food production. The responsibility rests not only with farmers, however, but also with the agri-business sector, consumers, and governments. The forging of a common vision between these interdependent players is critical to the long-term sustainability of agriculture and the environmental resources on which it depends.

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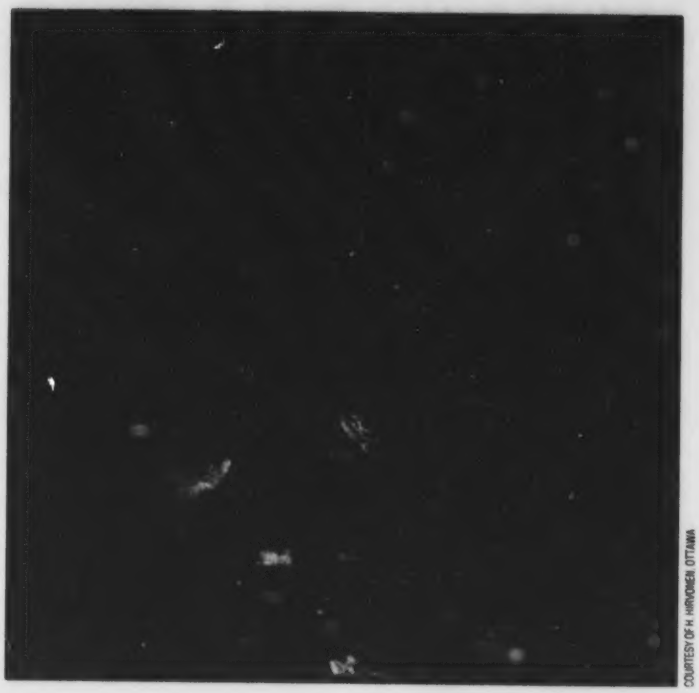

COURTESY OF H. HIRVONEN, OTTAWA

HIGHLIGHTS

The forestry sector is crucial to Canada's economy, contributing $20 billion to Canada's gross domestic product in 1989. Forests also provide habitat for wildlife and help to conserve water and soil, moderate climate, and purify the air.

■

The area of commercially productive forest in Canada that is logged annually increased from approximately 700 000 ha in the mid-1970s to over 1 million hectares in 1988. Although increased site preparation, tree planting, and stand tending have kept pace with increased logging, more land is logged each year than regenerates into commercially productive forest.

■

Close to 90% of all logging in Canada is carried out through the practice of clear-cutting. Although clear-cutting has proven to be an effective way to harvest and regenerate even-aged forests, some people feel it damages wildlife habitat, enhances erosion, is aesthetically displeasing, destroys cultural values, and is less sound in the long term than selective logging.

■

Two percent of all chemical pesticides used in Canada are used in forestry. The forest industry is now using *Bacillus thuringiensis* (B.t.), a biological control agent that is harmless to almost all nontarget species, for 60% of its spraying to combat insect infestations.

■

Pulp and paper mills have been able to reduce certain forms of pollution in their effluents and remain productive. For example, discharges of suspended solids fell from 4 500 to 600 t/day between 1960 and 1988, even though the mills doubled their production of pulp.

■

Chlorinated organic compounds (dioxins and furans) will soon be strictly controlled in effluents from kraft mills that bleach pulp using chlorine when revised regulations on wastewater are implemented.

■

In 1990, a new federal Department of Forestry was created to "promote the sustainable development and competitiveness of Canada's forest sector for the well-being of present and future generations of Canadians." Provincial and federal forestry ministers are sponsoring a new national forest strategy to be completed in 1992. Based on broad public input, it will direct activities for the sustainable development of Canada's forests.

■

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> ". . . we first must have a biologically sustainable forest before we can have an economically sustainable yield (harvest) of any forest product, be it wood fibre, water, soil fertility, or wildlife."
>
> — C. Maser (1990a)

BACKGROUND

The forests of Canada comprise some of the major forest ecosystems in the world. A variety of human activities have an impact on the forest, including harvesting, manufacturing, recreational use, and conversion of forests to other land uses. Pollution from distant human activity also affects the web of life in the forests. Canadians want to understand the effect of human activity on the size and nature of the forests in Canada and to recognize how the management of Canada's forests affects the Canadian and planetary environments.[1]

Canada has been called a "forest nation" with good reason (Rowe 1972). Its softwood forests rank second in the world in volume, behind those of the Soviet Union. Almost half of Canada's total land area either supports forest or is capable of doing so. Forest lands occupy 453 million hectares (equal to 4.53 million square kilometres) or 45% of Canada's total area (Forestry Canada 1990*a*).

Figure 10.1 outlines the geographical areas in which the eight major types of forest communities are found. Each "forest region" has a characteristic climate and its own combination of tree species, although the borders of these regions are not sharply defined. The map does *not show the true extent* of forest in Canada: some land within each region has been converted to other uses, including farm land and settlements.

Once every five years, Forestry Canada, in cooperation with the provincial and territorial forestry departments, publishes a national inventory of Canada's forests. The inventory looks at 88% (398 million hectares) of Canada's forests[2]; 12% is not inventoried because it does not produce much wood fibre.

Of the 398 million hectares, 244 million hectares are classified as "productive forest lands," which means that these lands can produce commercially valuable crops of timber reasonably quickly. In 1986, "stocked"[3] productive forest land covered 216 million hectares; of this area, 96.5 million hectares, an area about the size of British Columbia, were covered by trees of harvesting age — "mature" and "overmature" in forestry terms (defined in note to Table 10.1) — and not under protected status from logging. Table 10.1 shows the area of productive forest by "maturity class" and the quantity of wood fibre in each class. Canada's forests have traditionally been described in commercial terms. The need for a broader description of Canada's forests, reflecting timber and nontimber values, has been recognized and is the subject of further review by Forestry Canada and provincial forestry agencies.

Fewer data are available on the nontimber values of Canada's forests. Canadian forests are made up of much more than trees. Soil, water, air, and living organisms — from fungi to people — all have important ecological functions in both natural and managed forests. Canada's diverse living resources include 131 tree species, over 4 000 other vascular plant species, nearly 200 mammal species, almost 580 bird species, over 80 different amphibians and reptiles, as well as almost 48 000 known species of insects and other invertebrates. A vast number of these species spend at least a portion of their lives in the forest. As human populations increase, the demand for recreation in forested areas has also increased. In recognition of nontimber values, commercial logging is not

---

[1] The data in this chapter have some limitations. Forestry statistics are based largely on data provided by provincial governments, and provinces define forestry terms differently (Haddon 1988) and do not necessarily collect their data in the same year. Our data are the most recent available, and we have tried to maintain uniformity of meaning. The Canadian Council of Forest Ministers is committed to expanding, updating, and standardizing forestry data through the creation of a National Forestry Database to better describe Canada's forests to Canadians.

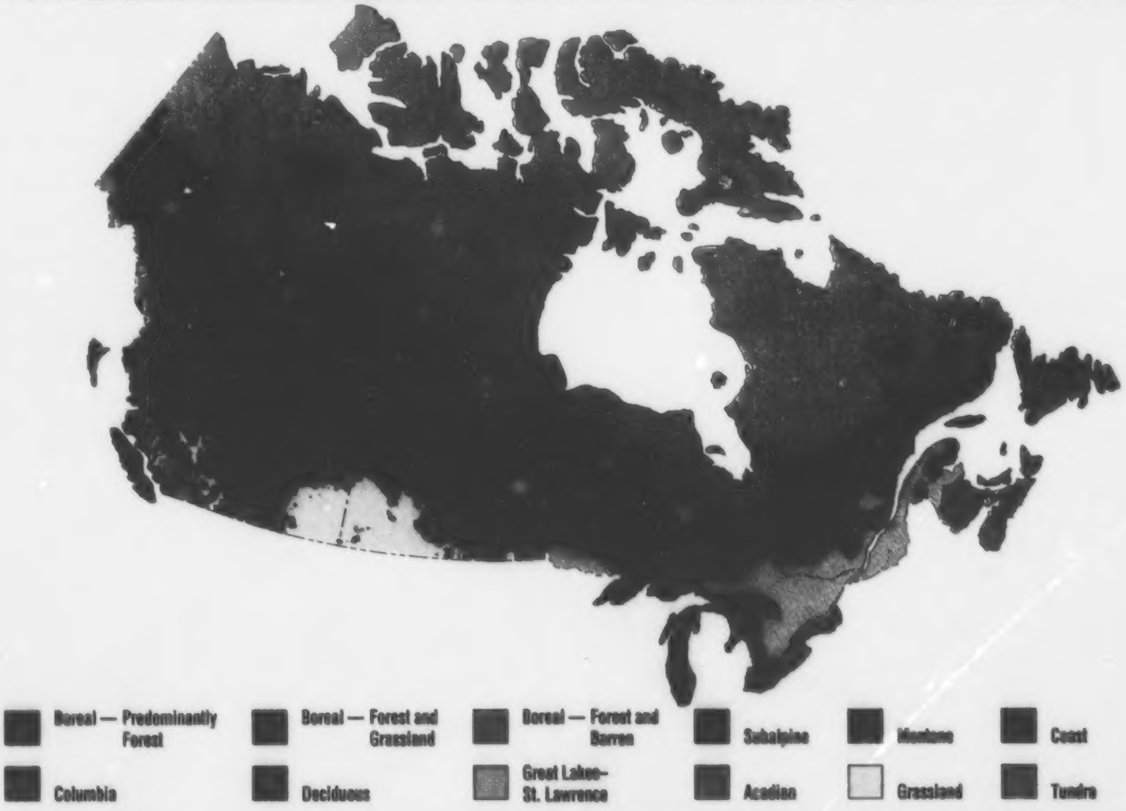
[2] The 88% includes both Crown-owned and privately owned land. More than 90% of Canada's forest lands are public lands.

[3] "Stocked" forest land means forest land supporting tree growth.

Figure 10.1

The eight forest regions of Canada

Forest region	Ecological description
Boreal Forest	This largest forest region in Canada occurs within a continental climate with cold winters and hot summers. Black and white spruces and tamarack dominate. Balsam fir and jack pine are prominent in eastern and central areas, with subalpine fir and lodgepole pine typical of the northwest.
Subalpine Forest	The climate in the mountain uplands of Alberta and British Columbia may be quite variable. Englemann spruce, subalpine fir, and lodgepole pine are characteristic.
Montane Forest	The climate of the plateau in central British Columbia and of some valleys and hill ranges of southwestern Alberta is dry. Interior or "blue" Douglas-fir, lodgepole pine, Englemann spruce, and trembling aspen are common.
Coast Forest	The Pacific coast has a moist oceanic climate. Trees grow larger and faster here than in any other region of Canada. Red cedar, western hemlock, Sitka spruce, and coastal Douglas-fir are predominant. In drier areas, the only arbutus and Garry oak found in Canada occur. Red alder and bigleaf maple are also common.
Columbia Forest	Parts of interior B.C. , including the Kootenay, Thompson, and Fraser river valleys, have a wet climate. Principal trees include western red cedar and western hemlock, along with substantial western white pine, Douglas-fir, and grand fir.
Deciduous Forest	Southwestern Ontario has a milder climate than most of central Canada. This is the northerly extension of large deciduous forests in the United States. Major species include sugar maple, beech, white elm, butternut, and basswood. Trees at their northern limit include tulip tree, cucumber tree, pawpaw, red mulberry, coffee tree, black gum, and sassafras. This region is the most diversified of all regions in terms of species variety. Very little of the original forest remains due to agriculture and urbanization.
Great Lakes– St. Lawrence Forest	This region occupies the temperate climate that characterizes the shores of the Great Lakes and the St. Lawrence and Ottawa river valleys. Principal species include sugar maple, eastern white pine, red pine, eastern hemlock, and yellow birch. Red maple, red oak, basswood, and white elm, together with many other hardwood species, are common.
Acadian Forest	This region occupies the oceanic climate of the Maritime provinces. Red spruce, associated with balsam fir, yellow birch, and sugar maple, is the characteristic species. Common constituents include, among others, red pine, white pine, eastern hemlock, and white and black spruce.


Boreal — Predominantly Forest
Boreal — Forest and Grassland
Boreal — Forest and Barren
Subalpine
Montane
Coast
Columbia
Deciduous
Great Lakes–St. Lawrence
Acadian
Grassland
Tundra

Source: Rowe (1972).

TABLE 10.1

The area of inventoried, stocked, productive, nonreserved forest and the quantity of wood fibre thereon, by "maturity class," in 1986

Area class	Atlantic provinces	Que.	Ont.	Prairie provinces	B.C.	Yukon and N.W.T.	Canada
A. Maturity class (000 000s ha)							
Regeneration	3.74	7.38	1.18	4.13	1.69	1.69	19.79
Immature	5.42	9.20	12.33	23.26	15.00	12.55	77.76
Mature	4.59	22.67	11.56	10.51	28.28	5.72	83.33
Overmature	1.19	–	7.61	4.25	0.08	0.02	13.14
Uneven-aged	0.22	0.15	0.01	–	–	–	0.37
Unclassified	5.14	12.45	0.01	4.44	–	–	22.04
Total	**20.30**	**51.85**	**32.70**	**46.59**	**45.05**	**19.98**	**216.43**
B. Maturity class (000 000s m³)							
Regeneration	1	119	1	10	9	–	140
Immature	357	734	930	1 549	1 604	452	5 625
Mature	546	2 167	1 465	1 742	7 226	473	13 619
Overmature	142	–	1 132	814	28	1	2 117
Uneven-aged	15	18	1	–	–	–	34
Unclassified	306	1 187	–	125	–	–	1 618
Total	**1 367**	**4 225**	**3 529**	**4 240**	**8 867**	**926**	**23 153**

Note:

Regeneration: A new crop of trees, generally less than 1 m high.
Immature: Trees or stands grown beyond the regeneration stage but not yet at a harvestable age.
Mature: Stands or trees that are suited to harvesting and are at or near rotation age.
Overmature: Stands or trees past rotation age. Openings in canopy as a result of mortality becoming apparent.
Uneven-aged: Stands or forest types in which intermingling trees differ markedly in age.

Source: Forestry Canada (1990*b*).

permitted on about 12 million hectares of the inventoried forest land (9 million hectares or 4% of the productive forest land), which is set aside in parks (although logging *is* allowed in *some* types of parks) and other reserves.

CANADIAN DEPENDENCE ON FORESTS

Economic returns from wood products

In 1988, Canada ranked first in the world in production of newsprint, second for wood pulp, and third for softwood lumber. In the same year, Canada's manufactured forest products shipments were valued at $49 billion. Forestry sector exports in 1989 were valued at $23 billion, representing 17% of all Canadian exports. In no other industry do exports so greatly exceed imports. This trade surplus is more than the agriculture, energy, fisheries, and mining surpluses combined.

Forest products contribute significantly to regional and rural economies. They provide the economic base for almost 350 single-industry communities. In total, about 900 communities rely directly on the forest industry to some extent (Pharand 1988).

Employment and subsistence

Employment in forestry and forest-related industries was 900 000 in 1988. In the same year, total salaries and wages for the primary and manufacturing components of the forestry sector approximated $9.6 billion.

In 1985, 16 520 farm woodlots with an area of 2.79 million hectares allowed farmers to supplement their incomes by growing trees and selling forest products, such as fuelwood and maple syrup. An estimated 500 000 private forest owners manage 22 million hectares of productive forest land.

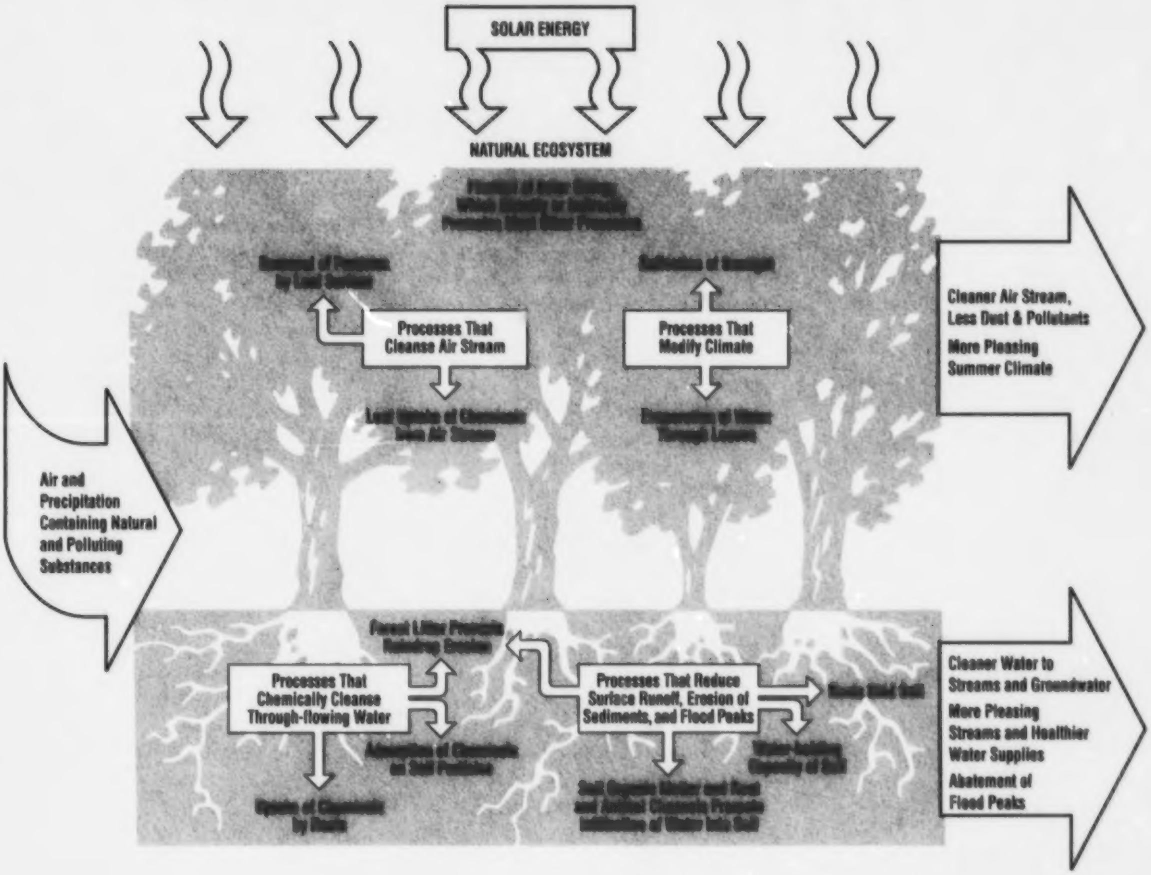
Some rural Canadians, especially native people, still spend at least part of the year involved in traditional hunting and fishing activities. In addition, there are many other Canadians who supplement their diet with fish, game, maple syrup, and fungi and plants collected in wooded areas, and who cut wood for heating and cooking.

Recreation

Recreational pursuits, such as park visitation, bird watching, nature photography, hunting, hiking, canoe tripping, and cottaging, often take place in the forested landscape. Forests near cities are increasingly valued by city dwellers, who seek relief from artificial

FIGURE 10.2

Forests, powered by the sun, purify air and water, conserve water, and regulate climate


SOLAR ENERGY
NATURAL ECOSYSTEM
Fixation of Solar Energy Which Directly or Indirectly Promotes Most Other Processes
Removal of Particles by Leaf Surface
Processes That Cleanse Air Stream
Leaf Uptake of Chemicals from Air Stream
Reflection of Sunlight
Processes That Modify Climate
Evaporation of Water Through Leaves
Air and Precipitation Containing Natural and Polluting Substances
Cleaner Air Stream, Less Dust & Pollutants
More Pleasing Summer Climate
Forest Litter Prevents Raindrop Erosion
Processes That Chemically Cleanse Through-flowing Water
Adsorption of Chemicals on Soil Particles
Uptake of Chemicals by Roots
Processes That Reduce Surface Runoff, Erosion of Sediments, and Flood Peaks
Roots Bind Soil
Water-holding Capacity of Soil
Soil Organic Matter and Root and Animal Channels Promote Infiltration of Water into Soil
Cleaner Water to Streams and Groundwater
More Pleasing Streams and Healthier Water Supplies
Abatement of Flood Peaks

Source: Bormann and Likens (1979).

surroundings. Recreation in remote wilderness areas has growing appeal for the same reason.

Scientific information

Relatively pristine forests are useful to scientists, who study the dynamics of forest ecosystems in order to improve management of forested lands. Also, by monitoring changes in growth patterns of trees, scientists can detect adverse impacts of human activity, such as air pollution and climatic change. Forestry researchers search virgin and naturally regenerated forests for unusual plant genes, as they attempt to produce, through hybridization, trees with desirable qualities, such as disease resistance or the ability to grow on poor soils.

Habitat for wildlife

For many wildlife species, including some species of freshwater fish, forest habitat is vital for survival. Canada supports most of the world's woodland caribou, wolves, grizzly bears, and wolverines, all of which, for at least part of the year, are forest dwellers.

Not only is wildlife dependent on forested habitat, the reverse is also true. Bacteria, birds, insects, fish, invertebrates, and mammals are integral parts of forest ecosystems, performing functions such as nitrification (making atmospheric nitrogen available to plants), pollination, and seed dispersal.

Water and soil conservation

Forests act as reservoirs and purifiers of water: litter on the forest floor traps water and prevents runoff, logs and mosses become waterlogged, shaded soils dry out only slowly, and roots take up water; both roots and soils take up chemicals from the water (Fig. 10.2).

Tree cover delays the melting of snow, encourages accumulation of snow under breaks in the forest canopy, and influences the flow of water. The headwaters of many rivers are in forested water catchments.

Where there are forests, water runoff is impeded and the roots of the vegetation anchor valuable topsoil. Topsoil is formed from the annual litter that falls from the trees and from decomposing flora and fauna. A layer of litter (duff) on the forest floor is gradually broken down into earth by microorganisms, and the nutrients released by the processes of decay enrich the underlying mineral soil. The process is site specific; the type of soil that forms is determined by the tree canopy above in addition to site characteristics, such as amount of shade, amount of rain that reaches the ground, drainage, slope, and so on. Life in the soil is complex and important to forest productivity. For example, certain types of fungi (ectomycorrhizal fungi) that grow on the roots of healthy trees increase the trees' ability to absorb nutrients. These fungi are spread in the forest by mammals, such as northern flying squirrels, that eat the fruiting bodies of the fungi and spread the spores of the fungi throughout the forest in their feces (Maser 1990*b*).

Climate control and air purification

In addition to mitigating the effects of drought by acting as a reservoir, forest vegetation releases water vapour to the air, in a process known as transpiration (Fig. 10.2), thus affecting local humidity and tempering extremes of climate. Deforestation has been shown to increase air temperature (due to reduced absorption of solar energy by the vegetation) and speed and duration of wind (trees no longer act as windbreaks) and to cause shifts in regional and local rainfall patterns.

Plants absorb carbon dioxide, the chief culprit in global warming, store the carbon, and release oxygen. Forests also filter other pollutants from the air (Fig. 10.2). Consequently, forests play an important role in maintaining the quality of water, soil, and air.

Biodiversity

Biological diversity, or biodiversity, encompasses genetic diversity within species, species diversity, and ecosystem diversity. This diversity of living beings in Canada's forests is a fundamental measure of ecological health.

Canadian forests contain 131 tree species. Within each species, there is genetic variation, which may be considerable (e.g., white spruce and Douglas-fir) or relatively small (e.g., red pine). In some areas (e.g., the Gaspé peninsula of Quebec, the Queen Charlotte Islands in British Columbia) there are rare or unique plant populations in restricted areas (endemics), which may be relict or newly evolved populations. Hybrids sometimes occur naturally by the crossing of tree species that are closely related.

Foresters value genetic diversity and hybridization as resources for the promotion of superior trees (e.g., trees that grow better on poor soils, trees that are less susceptible to disease). Genetic diversity gives species the flexibility to adapt naturally to environmental changes, such as climatic warming and increasing pollution. The diversity of plant and animal species and associated landscapes gives the same flexibility to the forest as a whole.

THE CHANGING FOREST

No forest ecosystem is free from the forces of environmental change and disturbance. In the natural state, without human interference, the makeup of the forest changes as its biota adapt to new conditions and become established in new areas. The trees have their own cycles: the dominant tree species change over time (succession), until this established pattern (from pioneer to climax species) is interrupted by fire or other natural catastrophe and succession must start again, or until the forest reaches a state in which trees die of old age (climax forest), leaving gaps in the forest where seedlings can flourish. Thus, the forest is a patchwork of stands of different ages, areas, and species. This also includes ancient forests, which are made up mainly of long-lived trees, snags (dead standing trees), and logs.

Forest species have adapted to natural disturbance over many thousands of years. Canada's forests are exposed to an increasing pace and magnitude of human-caused pressures. Commercial activities, such as harvesting and silviculture, occur on about 0.5% of the commercial forest each year. Other human-caused activities, such as land-use change, tourism, recreation, and fires, along with global factors such as climatic change and air pollution, also modify the forest. These combined pressures and their pace may well test the resilience of certain forest areas.

Fire cycles and control

Historically, the major natural disturbance of Canadian forests has been wildfire. Only certain forests that seldom burn, such as shade-tolerant hardwood forests in eastern Canada, high-elevation forests, or the west coast rain forest, have tended to reach a climax state. Elsewhere, the forest was a mosaic of different age-classes, reflecting historical wildfire disturbances. For example, before 1939 the boreal forests in Alberta burned about every 50 years and the subalpine about every 60 years (Van Wagner 1978; Murphy 1985).

Whether forest fires are viewed as "bad" or "good" depends on the management objectives for the area affected. On the one hand, some species, like lodgepole pine and jack pine, are naturally dependent on fire, which releases the seeds from their cones and prepares a good seedbed by exposing the mineral soil. In addition, regeneration of red pine and white pine is improved by fire, which burns off the duff, reduces competition, and prepares a seedbed. After a fire, the wood ash contributes nutrients to the soil.

On the other hand, fires can seriously affect the wood supply for forest products industries, lessen the value of forests for human recreation, and threaten people's homes and subsistence. In recent years, about 10 000 fires annually have started across Canada, burning a total of 900 000 ha on average (Table 10.2), and about 25% of the burns have been in commercially productive forest. The year 1989 was worse than average: over 12 000 fires burned approximately 7.3 million hectares. Historically, more than half of all forest fires were caused by people. To protect people and commercially productive forests, Canada has become a world leader in forest fire detection and control.

TABLE 10.2

Forest losses to fire and insects

Fires	**Average 1984–86**	**1986**	**1987**	**1988**	**1989**
No. of fires	8 554	7 087	11 304	10 741	12 105
Area burned (000s ha)					
Total forest land	824	950	1 086	1 336	7 273
Productive forest land	209	312	313	640	2 339
Fire control expenditures ($ 000 000)					
Budgeted costs	137	109	116	142	165
Fire-fighting costs	108	102	155	185	270
Insects		**Hectares of productive land damaged (in 000s)**			
Spruce budworm	16 460	12 385	8 479	6 335	7 738
Forest tent caterpillar	2 177	2 007	3 813	8 350	10 715
Jack pine budworm	3 276	2 052	508	737	248
Mountain pine beetle	292	94	66	63	53
Gypsy moth	165	168	13	30	82
Hemlock looper	180	215	150	13	9

Source: Forestry Canada (1990*b*).

Insect damage to trees and tree diseases

All forests contain complex communities of insects and microorganisms. Those that weaken or kill trees are considered pests in managed commercial forests. There are many indigenous pests in Canada's forests, as in most forests in the world. Diseases usually strike trees that have already been weakened by various anthropogenic or natural factors, including insects. Insects and diseases may damage or kill many trees, but, with time, as conditions for infestation disappear (e.g., climatic conditions change, food supply for insects declines, predators on the insects increase), the forest reestablishes itself. Depending on the successional stage of the originally infected forest, the emerging forest may or may not be similar to the original one. Insect infestations are most often cyclical occurrences. Some of the more serious insect pests are the spruce budworm, the forest tent caterpillar, the jack pine budworm, the mountain pine beetle, the gypsy moth, and the hemlock looper.

As Table 10.2 shows, the most damage is caused by the spruce budworm, which prefers balsam fir. In Quebec alone, the last spruce budworm outbreak resulted in the loss of more than 200 million cubic metres of wood, the equivalent of five years of harvest at 1986 rates. Alarmingly, the average interval between outbreaks seems to be narrowing. The interval was 29 years between 1704 and 1877 (seven outbreaks); however, over the last 40 years, this interval has narrowed to about 11 years, despite large-scale spraying operations with insecticides (Blais 1965; Martineau 1984). Some observers have linked the increasing frequency of outbreaks to logging practices, such as selective cutting of spruce (leaving behind the spruce budworm's favourite tree, the balsam fir) and degeneration of stands when healthy trees were cut (Koroleff 1951, cited in Swift 1983).

Endemic populations of indigenous insects cause damage enough; however, when exotic disease-causing pests are introduced inadvertently, the consequences may be devastating. Existing stands are not adapted to them, and naturally occurring predators are nonexistent. Thus, destruction may be total. The introduced balsam woolly aphid is a serious pest on balsam fir, and the European winter moth is a threat to valuable hardwood stands in the Maritimes. The white pine blister rust, which in 1900 spread to Canada from Europe and Asia, is still responsible for considerable losses in growth of white pine (Maini and Carlisle 1974). The gypsy moth is a defoliator that was introduced into the United States in the mid-1800s and has since spread into Canada. It is a major concern for hardwood species such as oak, maple, and birch.

Air pollution

Some stresses caused by human activity, in particular atmospheric pollution, have the potential to cause widespread damage to the forest. Though the effects of atmospheric pollution on forest ecosystems are not fully understood, airborne pollutants known to damage these ecosystems include organic chemicals (pesticides, volatile organic compounds, and esters), sulphur dioxide, nitrogen oxides, and heavy metals. Ozone and fluorides are harmful when they are in direct contact with vegetation.

BOX 10.1

Sugar maple forests in eastern Canada

"Sugaring off" has long been one of Canada's rites of spring. European settlers learned from Canada's native peoples the process of collecting the sap from the sugar maple, then boiling off the water to produce maple syrup and sugar. Today, maple sugaring is an important seasonal industry in Quebec, Ontario, and the Maritimes.

Maple dieback has characteristic symptoms — dying of branch tips, premature yellowing, and dropping of leaves — leading to the death of the trees. Insects, diseases, and drought can contribute to the natural decline of stressed trees. However, in the last two decades, scientists and owners of maple forests have been studying the added effects of air pollution.

No direct cause-and-effect relationship can be shown experimentally between air pollution and maple dieback. A survey in Quebec showed that only 3% of maple forests have canopy loss in excess of 25%, but that 47% of stands have canopy losses from 11 to 25%. The survey also indicated that the extent of damage had been increasing.

Research into the causes of dieback began in 1986. The federal and Quebec governments are cooperating in a program to fertilize maple stands, which provides a temporary solution. Research indicates that the damage is due to a broad range of both natural and human-caused activities, including sudden fluctuations in temperature and lack of moisture and snow cover.

Sulphur dioxide and nitrogen oxides combine with water in the atmosphere to cause acidic precipitation. Much of the acidic precipitation in Canada is linked to sulphur dioxide emissions from coal-fired generating plants and smelters. About half of the sulphur deposition in Canada is transported by prevailing winds from sources in the United States. There is concern over nitrogen oxide emissions primarily because of their role in the formation of ground-level ozone and, secondarily, because of their effects on human, animal, and plant health and their role in acid rain, more correctly called acidic deposition (see Chapter 24).

Soil fertility is a vital factor in determining the relative sensitivity of a forest to acidic deposition. Because of its effect on soil chemistry (nutrients), acid rain decreases the vigour and growth of trees. This phenomenon can weaken maples suffering dieback as a result of natural causes (see Box 10.1).

In Canada, wet sulphate deposition (the amount of sulphate in rain, fog, and snow that precipitates onto the landscape) ranges from less than 10 kg/ha per year to more than 40 kg/ha per year. Critical deposition loadings (i.e., levels of deposition for any particular forest ecosystem above which damage occurs) have yet to be determined for Canada's forest lands. A large area of the Great Lakes–St. Lawrence Forest Region, with its mixed woods of pine, spruce, and hardwoods growing on already acidic soils, is in the 20–40 kg/ha per year wet sulphate deposition zone, making it vulnerable to degradation. Infertile soils also make the Acadian Forest Region in the Maritime provinces vulnerable. Large areas of the Boreal Forest Region, with its sensitive, nutrient-poor, acidic soils, are in the lower deposition zone of less than 10–15 kg/ha per year; however, even low levels of acidic deposition may be harming sensitive forest ecosystems, without our knowing it.

Forestry Canada has established an Acid Rain National Early Warning System (ARNEWS) to research and monitor forest – air pollution interactions (Magasi 1988). Currently, over 100 sites, largely in eastern Canada, make up this network.

Greenhouse effect

Scientists generally agree that there will be a significant increase in mean global temperature in the next 30–70 years. The concentration of carbon dioxide in the atmosphere is increasing at a rate of 0.5% per year (and likely to double in the near future), and levels of other "greenhouse gases," such as CFCs, methane, and oxides of nitrogen, are also rising.

This change in climate may profoundly affect Canadian forests. The increase in temperature and the reduction in soil water have the potential to change the distribution of trees and associated ecosystems. Some effects could be beneficial — for example, an increase in the length of the growing season. However, others surely will be negative. Fire will be more prevalent; the higher temperatures in spring and summer, and the warmer winters, may increase insect populations and the damage they cause.

Foresters have difficulty preparing for global warming due to the time it takes to grow a mature tree. Trees selected for the prevailing conditions at the time of planting may cease to thrive or die if the climate becomes unsuitable. If the amount of carbon dioxide in the atmosphere in 1991 were to double, it has been estimated that the boreal forest zone of western Canada would shift up to 900 km northward (Wheaton and Thorpe 1989).

The rate of increase in the amount of carbon dioxide in the atmosphere can be prevented or moderated in several ways. The reduction of fossil fuel use is the most obvious preventative approach. Building up forest biomass — by reducing deforestation or by reforestation — can also slow down the input of carbon into the atmosphere. This is an important reason to try to maintain forest biomass.

Although not a permanent solution to the global warming problem, a buildup of forest stocks, via new plantations and spontaneous growth, might buy time — perhaps several decades — in which to find other methods to limit carbon dioxide buildup and consequent global warming. In the meantime, much research on the changing climate is in progress in Canada and throughout the world (Harrington 1987; Wheaton *et al.* 1987; Environment Canada 1988; Addison 1988; Rizzo and Wiken 1990).

Land-use changes

Each year, some forests are lost to urban development, roads, energy corridors, and hydroelectric projects. Roads, railways, and energy corridors cross thousands of kilometres of forested land. Of the 576 dams in Canada, about 170 are in the boreal forest and 55 are in the montane forests of the Rockies. In Quebec, the second phase of the James Bay hydroelectric project may inundate several hundreds of thousands of hectares of forests.

Some of the forested land cleared by early European settlers in eastern Canada proved unsuitable for farming and is now reverting to forest. In southern Ontario, the area of forests has increased from 25 to 29% over two decades (Armson 1989). In the west, some forest lands are still being converted to agriculture.

Forest reserves

In the forestry sense and in this chapter, "reserved forest land" refers to land on which commercial harvesting is not allowed by law or by policy. About 9 million hectares of productive forest land and about 3 million hectares of unproductive forest land have been reserved in parks, wilderness areas, camping areas, and so on. There are 34 national parks (18 million hectares) and about 1 280 provincial parks (23.5 million hectares), some of which are largely forested; others do not contain much forest. The degree of protection in these parks varies. The Government of Canada has as a stated target the setting aside of 12% of the country as protected space.

The spatial pattern of our protected land is important in terms of both biodiversity and ecosystem health. Isolated islands of protected wilderness may not provide much protection to many species, particularly those that depend on large prey populations. Travel corridors are needed to provide access for wildlife among undisturbed areas. As well, species richness is also a good measure of general ecosystem health. Thus, the development of forest and other reserves across the country requires consideration not only of spatial characteristics but also of the ecological diversity within these reserves.

Logging

Amount logged

Wood fibre — Canada possesses a vast quantity of wood fibre. Consider that it takes 23.6 m^3 of wood to frame and floor an average Canadian home, and a national inventory reveals that 23 billion cubic metres of wood (of all kinds) are available for harvesting (Forestry Canada 1990*a*).

Each province plans how much of this wood it will allow to be cut every year. This annual allowable cut, or AAC, is based on the theoretical annual increment of merchantable timber after consideration of a host of factors, including quantity and quality of merchantable species, accessibility, and growth rates. In addition, many areas of productive forest may be excluded from the calculation of AAC because of site sensitivity or for their value as buffers, wildlife habitat, scientific study, recreation, or other resource use.

Private companies sign agreements with the provinces for the right to harvest certain areas under certain terms and conditions. Forest tenures require licensees to file detailed management and development plans, which specify the silvicultural techniques that will be used to regenerate logged sites, outline the mechanical and/or chemical methods that will be used to protect the next crop of trees, describe planned road construction, and so on. Overall, companies have increasing responsibility for forest management, including planting seedlings and tending and protecting forests. Provincial governments provide the regulations, guidelines, and advice to ensure that sound management practices are followed. Figure 10.3 shows the extent of existing tenures and proposals under consideration.

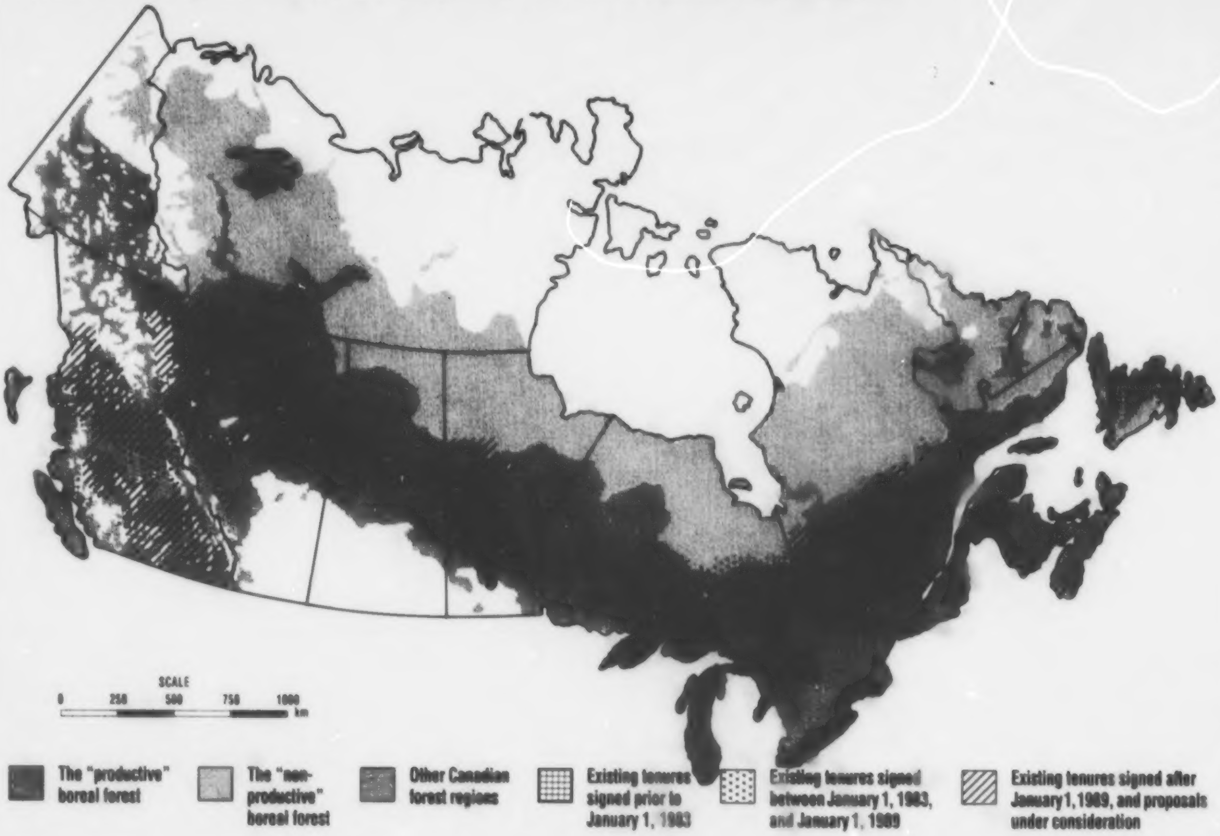
In the past, companies did most cutting on more accessible areas, which made good business sense if not always good forestry practice. These days, however, there is increased concern about evenly distributing the cuts in forest management areas. Also, efforts are being made to classify the sites and to protect ecologically sensitive areas, such as sites on shallow soils and on steep slopes, critical wildlife habitats, old-growth forests, and sensitive water catchments.

As Table 10.3 shows, Canada's harvest levels remain below the AAC for both softwood and hardwood species, although softwood harvest levels and AACs are now converging. Provincial governments are constantly reassessing AACs in light of ecological and social constraints, economic availability, sustainability, and changes in technology. Local shortages of high quality softwoods for lumber exist in some regions. New technologies will allow increased use of hardwood species for commercial purposes.

Area — Annual area logged in Canada has increased from approximately 700 000 ha/year in the mid-1970s to over 1 million hectares per year in 1988. The area logged has increased in all provinces since the mid-1970s: Quebec had the largest increase, from 135 000 ha in 1975 to 315 000 ha in 1988; British Columbia's increase was 87 000 ha to a total of 244 000 ha in 1988; and Ontario's increase was about 50 000 ha to 237 000 ha. Volumes of timber supported on a given area of land vary widely across Canada, from an average of 86 m^3/ha in the Boreal Forest Region to 300 m^3/ha in the Coast Forest Region of British Columbia. Recent negotiations for new forest industries in the Prairie provinces will lead to increased logging there in terms of both area affected and timber removed.

FIGURE 10.3

Forest tenures granted to private companies and tenures under consideration


SCALE
0
250
500
750
1000
km
The "productive" boreal forest
The "non-productive" boreal forest
Other Canadian forest regions
Existing tenures signed prior to January 1, 1983
Existing tenures signed between January 1, 1983, and January 1, 1989
Existing tenures signed after January 1, 1989, and proposals under consideration

Source: Wylynko (1991).

Clear-cutting: a common but controversial practice

Both the amount of forest harvested and method employed have ecological implications. In 1988, 190 million cubic metres were logged in Canadian forests. The vast majority of all harvesting (89.6%) is done by the clear-cut method, whereby all the trees in a stand are cut down. In contrast, selective harvesting, the removal of individual or small groups of trees from the forest, accounts for a mere 6.7%; the other 4% is seed tree and shelterwood cutting (Kuhnke 1989).

Clear-cutting has been the subject of widespread public concern, leaving as it does an appearance of devastation. However, clear-cutting has proven an effective method to harvest and renew even-aged stands of fire origin, especially those of such early successional (pioneer) species as aspen and poplars, lodgepole and jack pine, and black spruce. Jack pine require heat to release seeds, and clear-cutting sets the stage for prescribed burning. Pioneer species require lots of light to grow, and, in most cases, clear-cutting provides full sunlight for seedlings.

Clear-cutting, as well as being economically viable for many forest stands, allows for relatively easy site preparation and for establishment and tending of a new regenerating forest. However, if not done properly, clear-cuts can inhibit natural regeneration. Soil erosion may affect streams and rivers causing siltation of fish habitat. Clear-cuts in ancient forests effectively destroy these microecosystems, which may never regain their original character. To complicate matters, scientists do not always agree on the best design for clear-cut areas. For example, woodland caribou require old-growth forest habitat. Some biologists think that when their habitat is logged they will do best with small clear-cuts linked by continuous old growth, whereas others argue for logging done in vast chunks, so that, as each chunk is cut and grows back, the animals always have an unbroken expanse of suitable habitat (Van Tighem 1990). Many questions like this one remain to be answered.

Only through increased research efforts can we develop better insights into the maintenance of healthy forest ecosystems and their species.

Site-specific ecological factors and characteristics of the tree species proposed for renewal must be taken into account when clear-cutting is considered. Factors such as as degree of shade tolerance, wind, moisture, and heat influences, prospects of vegetative competition, and wildlife needs may make some form of selective or multi-stage harvesting preferable to clear-cutting, both ecologically and economically, to ensure the long-term sustainability of the forest.

Full-tree harvesting and nutrient balance

Inevitably, logging removes some nutrients from forest sites. However, most of the nutrients in trees are contained in the foliage, fine twigs, and fine roots, which used to be left at the felling site. When the soil has 50–80 years between clear-cutting operations to recover, the loss of trunk nutrients has not been found to significantly affect forest land productivity. More recent logging techniques involve closer rotation ages. In addition, modern logging equipment, such as feller-bunchers, has made it more economical to remove the whole tree, including nutrient-rich branches and leaves. In this method of full-tree logging, trees are not delimbed and topped at the felling site but are skidded to a cleared landing, where branches are removed.

There is an increased awareness of the potentially significant nutrient loss associated with this practice. For certain sites in eastern Canada and the United States, removal of such nutrients as phosphorus, potassium, calcium, and nitrogen was 200–400% greater for whole tree removal than for conventional clear-cutting (Freedman 1981). Maser (1990*b*) points out that this kind of forestry practice will result in decreased forest productivity and will ultimately impair our efforts towards sustainable development.

The annual allowable cut (AAC) and harvest, 1970–89

Year	Softwood (millions m^3)		Hardwood (millions m^3)		Total (millions m^3)	
	AAC	Harvest	AAC	Harvest	AAC	Harvest
1970	195.8	110.7	32.6	10.8	228.5	121.4
1971	–	109.0	–	10.7	–	119.7
1972	–	112.5	–	11.6	–	124.1
1973	–	130.9	–	13.0	–	143.8
1974	–	125.7	–	12.2	–	137.9
1975	–	104.6	–	10.6	–	115.3
1976	176.9	128.3	39.6	10.8	216.5	139.1
1977	205.0	133.7	72.0	11.6	276.3	145.3
1978	205.4	143.1	50.9	12.0	256.3	155.1
1979	173.8	148.2	54.2	12.8	228.0	161.0
1980	205.0	142.6	–	12.8	205.0	155.4
1981	–	132.0	–	12.5	–	144.6
1982	–	115.9	–	11.2	–	127.0
1983	166.7	143.9	40.4	13.0	207.1	156.9
1984	–	153.4	–	14.1	–	167.5
1985	–	154.5	–	14.2	–	168.7
1986	165.6	161.9	59.3	15.2	224.9	177.1
1987	–	176.1	–	15.5	–	191.6
1988	174.7	174.0	58.5	16.3	233.2	190.3
1989	166.0	174.6	–	16.8	166.0	191.4

Source: Statistics Canada and Forestry Canada; Runyon (1991).

Impacts of logging on wildlife

Logging has the potential to create habitat diversity in the absence of forest fires, but it can also quickly destroy valuable wilderness habitat that has taken many years to develop. The forest in its variability provides habitats for a great diversity of wildlife species. To meet its fundamental needs for food, shelter, escape, and breeding, each wildlife species has its own requirements and preferences for tree and plant species, successional stage, and mixture of forest cover. For nonmigratory and nonhibernating species, suitable winter range conditions are especially important. The impact of logging on wildlife is therefore a mixed one, tending to favour those species whose preference is for edge conditions and earlier successional stages, while creating problems for those dependent upon old-growth conditions, such as woodland caribou and marten. On the west coast, studies indicate that species such as the Spotted Owl and Marbled Murrelet depend on mature forests for their habitat. Migratory birds that winter in rapidly disappearing tropical rain forests and breed in Canadian forests are especially at risk. The pressure on wildlife extends outside the area logged and does not always take the form of loss of habitat: for example, the construction of logging roads may be hazardous to wildlife because it opens up new territory to hunters, anglers, and other visitors.

Forestry–wildlife conflicts are becoming integral considerations in the early planning stages of most forestry operations. Certain silvicultural practices, such as the maintenance of streamside green belts, provision of travel corridors, protection of areas critical to a species, and leaving of snags, can help to lessen the impacts on all wildlife. As dying trees with nesting cavities

[illegible]

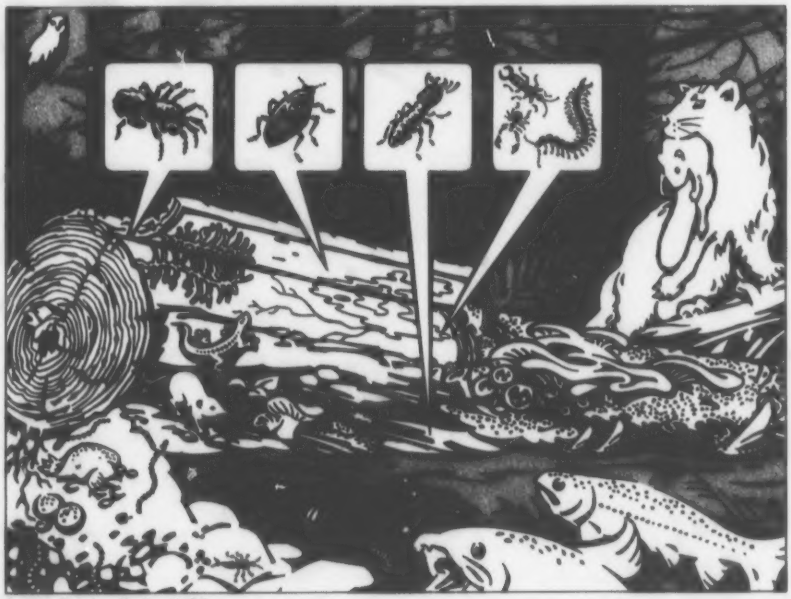
The Haida people and ancient forests on Moresby Island, B.C.

Located in the southern part of the Queen Charlotte Islands, the newly declared South Moresby/Gwaii Haanas National Park Reserve has been established on an area withdrawn from logging by the concerted efforts of the Haida people, who have occupied the area for 10 000 years. This example of old-growth temperate rain forest contains some of the world's largest Sitka spruce, western hemlock, and western red cedar and harbours 39 endemic species or subspecies of plants, animals, fish, and insects. The abandoned Haida village of Ninstints, which displays the largest array of totems still standing in their natural and cultural setting, has been declared a World Heritage Site. The case of South Moresby/Gwaii Haanas (which means "island of wonder and beauty") underlines the wide range of values assigned to the forest.

FIGURE 10.4

The ecological functions of a dead and decaying tree trunk on the floor of B.C.'s coastal forest

Dead logs support an amazing number of species, including fungi, spiders, beetles, and centipedes.



Source: Based on Findley (1990).

become rare, artificial nesting boxes become more important. The partial cutting ideas of Franklin (1990), including leaving of logging debris, are also designed to enhance habitat diversity and reduce impact on the old-growth-dependent species. Timing of logging operations in critical areas can also help to avoid conflicts between timber extraction and wildlife.

Erosion

Today's methods of logging, if not properly planned, can lead to serious problems with erosion. As late as the early 1950s, wood was cut in winter, hauled to rivers by horses, and floated out in the spring. The soil, protected by snow during logging, was not damaged (although the rivers were). Now, heavy machinery and poorly planned, constructed, and maintained access roads and skidding trails have caused soil erosion. Where erosion is caused by forestry operations, Freedman (1982) stated that 37% was associated with roads, 55% with skidding, and 8% with yarding (log storage). Governments and industry have developed environmental guidelines and design criteria to minimize erosion. Licences and permits for harvesting timber spell out such guidelines and regulations. In addition, governments have regulations in place that stipulate the use of buffer zones of trees adjacent to streams and lakes and the avoidance of (or adherence to strict rules of extraction on) steep slopes. New forest machinery that does not compact the soil so much is also helping to minimize problems of soil erosion.

Ancient forests

The age and composition of ancient forests vary according to their location. Concern about the conservation of old growth (trees or stands considered past their maturity) centres on the ecological and cultural heritage values of old growth and its importance in terms of biodiversity (see Box 10. 2). Much of the public focus has been on the rain forests of the west coast. However, boreal forests also contain areas of old growth.

Recent ecological studies (Franklin 1989) have shown that the ecology of old-growth forests is extremely complex and includes "an incredible diversity" of invertebrate life, especially insects that are predators or parasites on other insects. Many distinctive plants or animals seem to be largely dependent on these ecosystems.

Some of the present old-growth stands contain trees of impressive size, with ages in west coast stands approaching 1 000 years. Franklin (1989, 1990) suggests 200 years as the point at which old-growth conditions develop in Douglas-fir. Maser (1990*b*) points out that one-third of the useful existence of one of these forest giants is after it dies and becomes a snag and/or a fallen log. Figure 10.4 illustrates some of the ecological functions of a dead and decaying tree in the ancient forest.

West coast old-growth forests are valued by loggers for the size and standing volume of timber and, consequently, the jobs that these forests represent. Environmental groups, on the other hand, argue the importance of preserving old-growth ecosystems, especially those along the British Columbia coast.

Old-growth forest also exists elsewhere in Canada. In particular, the Temagami region of central Ontario still contains a few large stands of the ancient white and red pine forests that, at the turn of the century, were considered the best pinery in central Canada (Hodgins and Benidickson 1989). Some experts feel that it was the harvest of eastern white pine that provided the economic strength required to confederate the provinces (Aird 1985). Quinby (1990) defined what criteria a stand in the white pine forest in the Temagami region must meet to qualify as "old growth": it must be over 140 years old, have over a specified number of logs and snags, and have experienced minimal human disturbance.

Clear-cutting ancient forests represents a dramatic change of ecosystems that have historically been disturbed very little. The lands on which they are growing are recognized for their productivity; however, the projected length of the next cutting cycle (50–80 years) means that the old-growth ecosystem will not return. Franklin (1989, 1990), for example, has suggested a partial-removal harvesting system in coastal Douglas-fir forests, which would help to more quickly re-establish ecological diversity, as well as maintaining habitat for old-growth-dependent wildlife.

Forest renewal

Amount renewed

Earlier this century, it was commonly assumed that the logged forests would regenerate naturally. Most did, but often with trees or shrubs that were not commercially valuable. In the early 1900s, attempts were made to restock areas that had been harvested or burned and subsequently had failed to regenerate with commercially valuable species, but, by 1925, little success had been achieved.

Artificial regeneration increased after World War II, and, by 1965, planting and seeding had reached 59 940 ha/year (Cayford and Bickerstaff 1968). From 1975 to 1988, an average of about 211 000 ha were planted each year, while direct seeding and natural regeneration were occurring on additional sites. In 1988, more than 730 million seedlings were planted on approximately 413 000 ha, an area about four-fifths the size of Prince Edward Island. The largest plantation programs took place in Ontario, British Columbia, and Quebec (Table 10.4). The most common species used were white spruce (35%), black spruce (19%), and jack pine (13%) (Forestry Canada 1990*a*).

Not all seedlings survive. Success rates for spruce and pine planted in 1983–86 averaged 65.1% and 79.8%, respectively. In that period, the success rates of direct seeding and natural regeneration on cutover lands were 59.2% and 53.9%, respectively. Allowing for these losses, during 1977–88, planting, direct seeding, and natural regeneration adequately restored about 67.7% of the cutover area of 10.6 million hectares harvested during that 10-year period (Forestry Canada 1990*a*).

Currently, it is estimated that over 80% of cutover forests are regenerating promptly, either naturally or artificially, an increase of 22% from the early 1970s. In 1988, it is estimated that the difference between the area logged and the area promptly regenerated to commercial standards was about 200 000 ha (Fig. 10.5). This does not include natural losses due to fire, insects, and disease, which affect an area of forest greater than that harvested each year. Most of these areas regenerate over time, following the natural succession route to a commercially productive forest. Areas that have not yet regenerated to commercial standards are still considered productive forest, capable of supporting healthy forest ecosystems, although they may not yet contain trees of commercial value.

Site preparation, planting, seeding, and stand tending, from 1984–86 to 1988

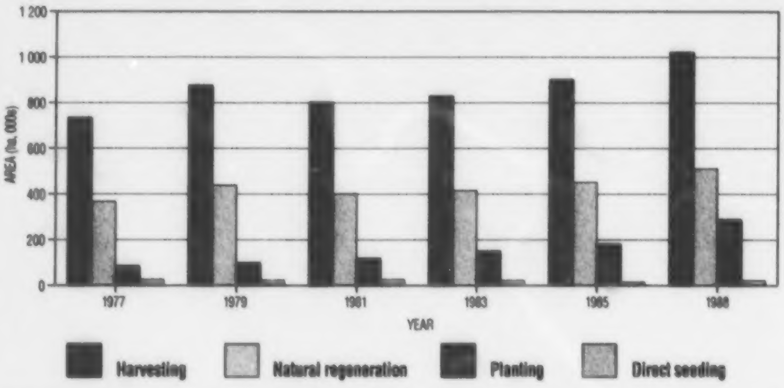
In 1988, industry and governments planted more than 730 million seedlings, mostly white spruce, black spruce, and jack pine, on over 413 000 ha. That number has since increased to 1 billion.

	Average 1984–86	**1986**	**1987**	**1988**
Site preparation (ha)	316 896	396 616	478 875	450 590
Planting				
-area (ha)	266 830	299 518	370 245	413 291
-Number of seedlings (000s)	466 735	540 857	656 468	731 332
Direct seeding (ha)	28 629	25 954	37 318	37 726
Stand tending (ha)	217 063	245 531	275 487	269 309

Planting in 1988	**Area (ha)**	**Seedlings (000s)**
Canada	413 291	731 332
Atlantic provinces	35 803	87 538
Quebec	99 055	226 200
Ontario	81 025	171 579
Prairie provinces	32 548	51 234
British Columbia	164 860	194 781

Source: Forestry Canada and Canadian Pulp and Paper Association (1990).

Area of harvesting and regeneration, 1977–88



Source: Forestry Canada and Canadian Pulp and Paper Association (1990).

In general, because of Canada's cool climate, the rate of growth in the country's forests is relatively slow. The largest region (the boreal forest) contains most of the wood fibre, but trees in the boreal forest do not grow quickly. For example, northern and temperate forests produce, respectively, about 4.2 and 6.6 oven-dried tonnes of wood per hectare per year, compared with 7.58 and 7.34 oven-dried tonnes of wood per hectare per year for tropical and subtropical forests (Jordan 1979; Timmins 1981). Nevertheless, in Canada, forestry techniques, such as the growing of hybrid poplars and red alder on good soils, can increase wood yield considerably, although this type of management is more expensive (Carlisle and Chatarpaul 1984) and, done on a large scale, would require drastic modifications of existing pulping processes, mill infrastructure, and transportation equipment. More intensive management could provide increased timber production. For example, the Scandinavian countries have managed their forests intensively for centuries, as have other European countries. Today, Swedish and Finnish tree farmers produce two or three times more wood per hectare of productive land than any province in eastern Canada. However, Scandinavia has very limited areas of natural forest.

In Canada, governments and industry have declared a commitment to timber renewal following logging. The responsibility may be met by provincial governments or, more typically now, may be delegated to the forest industry. Renewing the forest is one of Canada's biggest challenges in the coming years.

Site preparation

Since 1980–81, the percentage of the area logged that is subsequently prepared in some way for planting or seeding has steadily increased. Scarification, the mechanical breaking up of the forest floor (for example, by chains dragged over the forest floor), continues to be used over the largest area (62% of the 450 000 ha prepared in 1988), followed by prescribed burning (18%), herbicide application (3%), and a variety of mechanical treatments, such as crushing, ploughing, and slash windrowing (moving the cut branches into a heap).

Scarification is used to promote the regeneration of seedlings, where these are favoured commercially. The 450 000 ha "site prepared" in 1988 were nearly double the average area treated annually between 1975 and 1988 (Forestry Canada 1990*b*). Scarification introduces more oxygen into the soil and changes the activity of the soil organisms, soil acidity, water retention, soil temperature, and nutrient status.

Controlled fires are used to promote regeneration of trees such as jack pine, to remove weeds, and to clear logging debris. These may affect wildlife populations.

Forest plantations

Although the area of forest that is artificially regenerated in Canada each year has increased in recent years, it represents less than 0.5% of the productive forest land base. In stands that are intensively tended, trees take much less time to reach maturity than is the case in natural forests; however, growing trees quickly and harvesting them young can lead to problems with wood quality (Senft *et al.* 1985). Environmental concerns about plantation forestry relate to reduced resistance to insect and disease infestation, particularly in large monocultures, and a possible increase in the use of herbicides, insecticides, and fertilizers.

The loss of species diversity, in areas where plantations with fewer species are replacing previously heterogeneous forests, has ramifications for wildlife and may eventually diminish the gene pool. About 50% of the areas logged each year are regenerated naturally. The trend is towards an even greater use of natural regeneration to reduce costs and maintain diversity.

Stand tending and chemicals

There has been more emphasis on tending and protecting the regenerating trees with the aid of fertilizers, herbicides, and insecticides. Figure 10.6 shows the growth in use of chemical weeding between 1977 and 1988. It does not include insecticide use. It is noteworthy that only 2% of all chemical pesticides used in Canada are used in forestry.

Chemical weeding

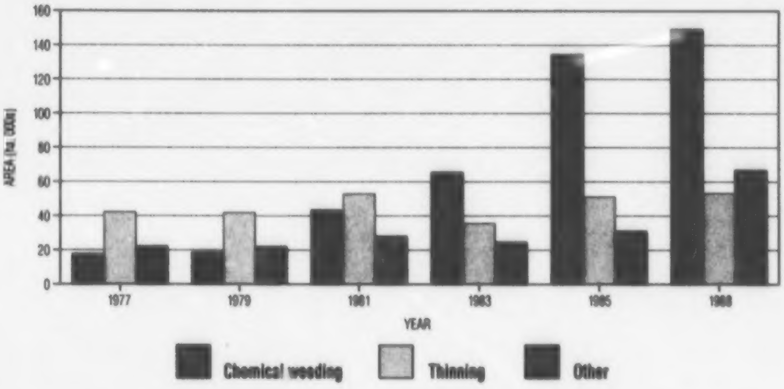
Weeding forests to reduce competition from hardwoods allows planted, seeded, and naturally regenerating conifers to more quickly attain what foresters have termed the "free-to-grow" stage. This can be done mechanically, manually, or by chemical herbicides, which are strictly regulated by the *Pest Control Products Act*. Mechanical and manual weedings are time consuming, thus expensive (up to $2 000/ha). In 1975–86, 523 565 ha of forests were treated with herbicides (Kuhnke 1989). Three herbicides, 2,4-D, glyphosate, and hexazinone, are registered for use in forest management in Canada; glyphosate is used in most provinces. These three herbicides affect nontarget plants. When important wildlife habitat is nearby, it is imperative to avoid these sites. The vegetation that feeds and shelters the wild animals and birds may be destroyed. The herbicide 2,4-D is not very persistent and is relatively nontoxic. Glyphosate is rapidly degraded and nontoxic to terrestrial animals but does affect a broad spectrum of vascular plants. Hexazinone tends to spread from the site where it is applied; therefore, Agriculture Canada has requested the manufacturer to monitor the effects of hexazinone on off-site vegetation.

Where other available methods are not practical, forest managers use these herbicides once or twice in the life cycle of the growing coniferous forest. Restrictions stipulate method of application, weather conditions at time of application, and the need for buffer zones around sensitive ecosystems. As with all pesticides, herbicides are approved for forestry use after testing and after Agriculture Canada has weighed the likely environmental and human health risks from the product against the anticipated benefits. Those products judged to be suitable for registration by Agriculture Canada are registered under the *Pest Control Products Act* and must also be approved for use by provincial authorities. Their use is monitored by several federal departments, although not systematically, as well as by the relevant provincial authorities.

[illegible]

Stand tending, 1977–88

Each year a small percentage of productive forest land is thinned, weeded, and fertilized. Most weeding is done using chemical herbicides. "Other" comprises largely manual and mechanical weeding and smaller amounts of fertilization, pruning, and drainage.



Source: Forestry Canada and Canadian Pulp and Paper Association (1990).

Insecticides: chemical and biological agents

Insecticides are used in Canadian forestry, particularly in the east, where they have been used to protect the standing crop of trees from insect pests. There are five registered chemicals: acephate, aminocarb, fenitrothion, trichlorfon, and carbaryl; and three biological control agents: *Bacillus thuringiensis* (B.t.), the nuclear polyhedrosis virus of the red-headed sawfly, and the nuclear polyhedrosis virus of the Douglas-fir tussock moth. Target insects are the eastern spruce budworm, the western spruce budworm, the jack pine budworm, the gypsy moth, and the eastern hemlock looper. B.t., which is harmless to people and most wildlife, accounts for 60% of the insecticides used to destroy forest insects. B.t. is relatively target specific, but it does affect *some* moth and butterfly larvae, not only those of the target pests.

Nearly 1.6 million hectares of forest were treated with insecticides in 1987, most of them in Ontario and New Brunswick (1.3 million hectares); however, this figure varies greatly from year to year, due to the cyclical presence of the spruce budworm. The focus of research in this area is the development of new ways of controlling insect "pests" with biological agents to minimize the use of toxic chemicals. Table 10.5 shows the area of forest pest control in all provinces and territories from 1975–76 to 1985–86.

As with herbicides, there remains considerable public and political concern about the effect of these pesticides on public health, wildlife, and forest dynamics. They affect wildlife and forest dynamics, in that the target insects are both part of the forest fauna and food for other species.

One of the most studied pesticides is fenitrothion; yet uncertainties and differing opinions on its harmful effects remain. Fenitrothion use has been linked with population decreases of honey bees and wild bees; these decreases cause a disruption of plant reproduction (Ernst *et al.* 1989). It is impossible to estimate whether forest bird populations are declining due to applications of fenitrothion, because counting methods are currently inadequate, but sporadic mortality of the most vulnerable and sensitive songbirds has been observed on sprayed sites. Also, studies indicate that a large proportion of birds in spray areas show a

Area of forest treated with pesticides, 1975–76 to 1985–86

The area of the forest treated with pesticides each year varies greatly from one province or territory to another and, over time, with the cycles of the target organisms.

Province or territory	Area of pest control (ha)											
	1975–76	1976–77	1977–78	1978–79	1979–80	1980–81	1981–82	1982–83	1983–84	1984–85	1985–86	Total
British Columbia[a]	1 785	2 667	2 384	2 908	2 287	1 564	3 830	0	2 374	3 948	3 488	27 235
Alberta	0	0	0	0	0	0	0	0	0	0	0	0[b]
Saskatchewan	0	0	0	0	0	0	0	0	12	434	0	446
Manitoba	0	0	0	0	0	0	0	0	0	428	760	1 188
Ontario	14 167	41 060	10 522	4 085	22 072	36 422[c]	22 477	28 685	43 770	47 280	10 339	280 879
Quebec	(2 800 000)[d]	(2 900 000)	(1 400 000)	(1 200 000)	(600 000)	188 511	705 164	1 298 495	1 253 606	712 282	698 343	13 756 400
New Brunswick	2 695 000	3 881 000	1 682 000	1 554 000	1 598 000	1 900 000	1 693 000	1 867 570	1 245 000	732 000	545 000	19 392 570
Nova Scotia	0	0	556	25 670	30 752	25 670	31 195	19 153	20 726	20 537	49 719	223 978
P.E.I.	0	0	0	0	0	0	0	0	0	0	0	0
Newfoundland	0	0	76 910	376 600	0	0	0	0	0	0	145 086	598 596
Yukon	0	0	0	0	0	0	0	0	0	0	0	0
N.W.T.	0	0	0	0	0	0	0	0	0	0	0	0
Canada	**5 510 952**	**6 824 727**	**3 172 372**	**3 163 263**	**2 253 111**	**2 152 167**	**2 455 666**	**3 213 903**	**2 565 487**	**1 516 909**	**1 452 735**	**34 281 292**

[a] Mainly dwarf mistletoe control, sanitation treatments, and spraying against western spruce budworm that began in 1983–84 using *Bacillus thuringiensis*.

[b] Does not include the control program started in 1979 against the mountain pine beetle that was conducted over an area of 32 000 ha.

[c] All figures from 1980–81 to 1985–86 include insecticides and herbicides.

[d] Numbers in parentheses are estimates.

Source: Kuhnke (1989).

pronounced inhibition of the brain enzyme, acetylcholinesterase. This enzyme is needed for proper nerve transmission. The depressions in enzyme levels, even when transient, have been associated with behavioural impairment and reproductive failure in forests treated with fenitrothion at twice the normal dosage. A decline in insect-eating forest birds could lead to increases in insect populations and the need for even more human intervention to protect forestry crops. There is insufficient evidence concerning the effect of fenitrothion on aquatic invertebrates.

Concerns about effects on human health from exposure to fenitrothion during normal use have not been substantiated by scientists (Ecobichon 1990). The use of fenitrothion is under special review, which should be completed in 1993, when a decision will be made by Agriculture Canada on its continued registration. There is strong opposition from the public (Box 10.3), including environmental groups, to the use of all chemical pesticides, particularly when aerial application is contemplated.

BOX 10.3

Public hearings in Quebec

In the mid-1980s, the Quebec Ministry of Energy and Resources held public hearings to look at health effects of chemical insecticides, particularly fenitrothion, when used in large-scale aerial spraying. The public opposed the use of pesticides and charged the government with a lack of long-term planning in forest management and insect population control and monitoring. As a result of the hearings, the government imposed a moratorium on aerial spraying of chemical insecticides in forests. Only B.t. was accepted for use in "urgent situations."

In 1990 and 1991, new public hearings were conducted in Quebec to examine health and environmental hazards and justification of large-scale uses of pesticides in forestry. The public was asked to comment on a document, *Strategy for forest protection*, prepared by the Quebec Ministry of Energy and Resources in collaboration with the forest industry and the Quebec Ministry of Environment, which called for much-reduced use of biocides and development of alternatives based on better understanding of forest dynamics.

Integrated pest management

Integrated pest management entails the use of silvicultural and biological control methods in lieu of chemicals, or in conjunction with chemicals, in situations where chemicals are deemed essential for protection. With provinces increasingly placing moratoriums on the use of chemical insecticides, B.t. is rapidly becoming the only practical alternative.

The public wants strongly reduced use of herbicides and insecticides. Alternatives must be based on understanding of the forest environment and pest population dynamics, on precise early detection and monitoring of pests, and on better forest management.

WATER AND AIR POLLUTION CAUSED BY WOOD PROCESSING

The backbone of Canada's forest economy comprises over 140 pulp and paper mills, nearly 1 100 sawmills and planing mills, and over 100 veneer, plywood, and panelboard mills (Forestry Canada 1990*b*). In addition, major expansions in the pulp and paper industry are planned for Alberta and Manitoba. For these latter cases, environmental concerns have led to further environmental impact assessment studies and/or public hearings prior to the construction of the mills. Operating mills have a variety of impacts on the environment.

Water pollution

The pulp and paper industry discharges wastes that contain pulping and bleaching chemicals, as well as solids such as wood fibres, into lakes and rivers and marine waters. The impact of pulp mill discharges on the aquatic environment varies with the quality of the effluent, disposal location (in relation to living resources), disposal method (surface discharge or submerged outfall), and habitat sensitivity. Problems of pH alteration and foam production are associated more with discharges to fresh water than with discharges to salt water, which has a greater natural buffering capacity.

The disposal of solids into both fresh and salt water is of concern. In 1988, pulp and paper mills across Canada discharged about 600 t (600 000 kg) of wood wastes into water every day (Fig. 10.7). These "suspended solids" tend to settle to the bottom, destroying habitat and smothering bottom-dwelling organisms.

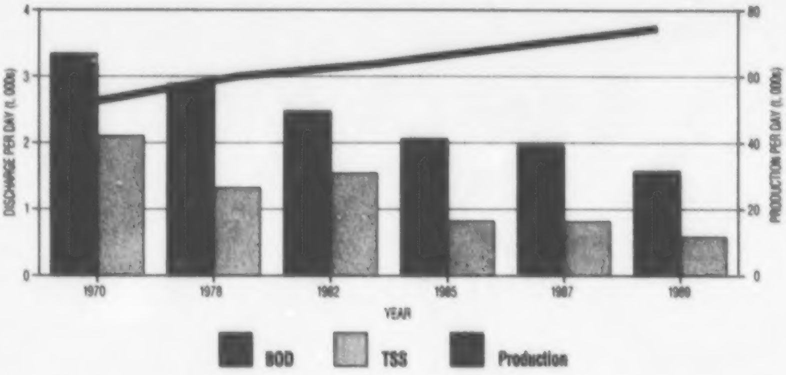
Mill effluent has also reduced the amount of dissolved oxygen in the water, upon which most aquatic organisms depend for their survival. In September 1985, dissolved oxygen levels at some sites in British Columbia were considered to be low enough to act as a barrier to migrating salmon. Healthy oxygen levels are beginning to return at these locations as changes in mill processes and pollution abatement technology are introduced (Porpoise Harbour near Prince Rupert is a case in point). In 1988, across Canada, mills caused about 1 900 t (1.9 million kilograms) of biological oxygen demand (BOD). Concerns about BOD persist at several pulp mill operations, although improvements have been made in effluent treatment and disposal. Revised regulations will force further declines in BOD, suspended solids, and toxicity.

Chemicals present in mill effluent may be both aesthetically displeasing, causing unpleasant odours or discoloration, and threatening to biota, because of their toxicity. Changes in the colour of river water are due to lignin, the natural glue that holds the wood fibres together. During processing into pulp, lignin is removed and some is discharged into the water. Older (bleached kraft) mills discharge about 260 kg of lignin per tonne of pulp produced. Also, bleaching pulp with chlorine, as is done at the bulk of Canada's pulp and paper mills, results in the formation of harmful substances, which, when discharged into a river, lake, or ocean, may accumulate in food chains. Among the most persistent and toxic by-products of the bleached kraft pulp mill process are certain isomers of dioxins and furans (e.g., 2,3,7,8-TCDD). The banning of chlorophenate-contaminated wood chips as feedstocks in pulp mills has greatly decreased the amount of dioxins and furans reaching the environment by this path (Box 10.4).

In 1988, Environment Canada, the Department of Fisheries and Oceans, and Health and Welfare Canada set up sampling programs in conjunction with the ongoing investigations of contaminants in fish-eating birds conducted by the Canadian Wildlife Service. Levels of dioxins and furans found in fish and shellfish near some pulp mills that use chlorine bleaching were high enough to pose a human health hazard if the species were eaten regularly. As a result, fishing grounds near two mills in Howe Sound in British Columbia were closed to crab, shrimp, and prawn fishing. The crab fishery near the Prince Rupert mill was also closed.

Effluents from pulp and paper mills, 1970–89

Solid wood wastes (suspended solids), discharged into water by pulp and paper mills, destroy habitat and smother bottom-dwelling organisms. Effluents from these mills also reduce the levels of dissolved oxygen in the receiving waters, so there is less oxygen available to fish and other organisms. The trend, in terms of release of total suspended solids (TSS) and biological oxygen demand (BOD), has decreased over the past 30 years, levelling off in 1985. This decrease has been accomplished despite the fact that daily production of pulp and paper has increased.



Source: Canadian Pulp and Paper Association.

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Chlorophenate use in sawmills and at lumber storage sites in B.C.

Foreign customers of B.C. lumber prefer unblemished wood; therefore, operators of sawmills and sites where lumber is stored, awaiting shipment, treat freshly cut lumber to prevent the growth of moulds and sapstain. Unfortunately, the penta- and tetrachlorophenates, the most commonly used antisapstain fungicides from the late 1940s until 1990, had adverse environmental effects.

Chlorophenates have reached the environment in several ways. The most direct routes have been the accidental spills into rivers and coastal waters and the chronic releases (rain falling on treated lumber sitting in storage yards and washing chemicals off the wood and into storm sewers) that occur under normal operating conditions.

A more indirect route, which is now being addressed by federal and provincial regulations, was the sale of chlorophenate-contaminated wood chips and shavings at pulp mills. The discovery of dioxins with five and six chlorines in fish, fish-eating crabs, and shellfish near bleached kraft pulp and paper mills led scientists to suspect that the antisapstain agents on the sawmill wastes used as feedstocks were the source of the contamination. When pulp mill operators recognized that the contaminated wood waste was a possible source for the dioxins and furans turning up in the environment, they stopped using it. This self-imposed restriction was reinforced by federal Canada-wide regulations prohibiting use of wood wastes contaminated with chlorophenates as feedstocks for pulp mills.

Chlorophenates, the water-soluble sodium salts of chlorophenols, are extremely toxic to aquatic life. Once they enter the food chain, they pose a threat to many other organisms, including humans, because dioxins and furans are present as micro-contaminants in all chlorophenate formulations. (This means that dioxins and furans are produced inadvertently in very small quantities during the manufacturing process.)

British Columbia is at the forefront of the antisapstain issue because so much of its lumber is exported and needs long-term protection. Table 10.B1 shows the decline in the number of B.C. sawmills using chlorophenates between 1988 and 1990, as the links between chlorophenates and dioxin concentrations in sediments and biota in receiving waters next to lumber mills became known. B.C. issued a regulation dealing with waste control of all antisapstain chemicals in August 1990. The number of mills using antisapstain chemicals has declined, but the total volume of antisapstain chemicals used may not have declined, because of increased volumes of lumber being exported. The table does not reflect use of chlorophenates at wharves and other treatment and storage yards.

On July 18, 1990, Agriculture Canada announced that antisapstain use of chlorophenates will be deregistered as of December 31, 1990. The alternatives, 2-(thiocyanomethylthio) benzothiazole (TCMTB) and copper-8 (Cu-8), do not contain dioxins or furans but are twice as toxic to fish as chlorophenates. Ecobrite and cedar extracts do not contain dioxins or furans, and they are less toxic to fish than chlorophenates.

Several new fungicides, none entirely environmentally benign, now have conditional registration. Mills that switch from chlorophenates may still be releasing them during the switch-over simply because they may still have drums of chemicals on site. Pentachlorophenol, known as PCP, is still used in the heavy-duty wood preservation industry, for treatment of railway ties, pilings, and poles.

TABLE 10.B1

Number of mills using antisapstain chemicals in B.C.

Antisapstain agent	January 1988	February 1989	November 1989	August 1990
Chlorophenates	73	20	5–7	0
TCMTB	13	19	19	22
Copper-8	2	18	23	26
Ecobrite	0	11	15	18
Cedar extract	1	0	0	0
Total	89	68	66	66

Chemicothermomechanical pulp (CTMP) mills, newer and more efficient than bleached kraft mills, use sodium sulphite, sodium hydroxide, and hydrogen peroxide, which produce an effluent that requires primary and secondary wastewater treatment to reduce the presence of organic matter and other suspended solids. CTMP mills discharge about 45 kg of lignin per tonne of pulp produced.

Scientists are striving to develop technologies that produce less or none of these pollutants. The Pulp and Paper Research Institute of Canada

(PAPRICAN) has proposed strategies that will, under full-scale mill operating conditions, make it possible to reduce the formation of dioxins and furans to nondetectable levels. The latest technologies include extended delignification, oxygen delignification, and chlorine dioxide substitution for elemental chlorine, thus reducing the production of highly toxic chlorinated organic compounds. A new CTMP mill at Meadow Lake, Saskatchewan, is proposing to install a closed system that will separate pollutants out of water before releasing it. (Eventually the concentrated pollutants may be reprocessed by industry or at least partially destroyed by incineration.)

Air pollution

Burning waste such as bark, branches, and sawdust at sawmills can affect air quality. More and more sawmills plan to burn wood wastes in cogeneration processes (electricity and/or pressurized water vapour for mill and kiln operations). Pulp mills that operate closed systems and do not release pollutants to the water may incinerate the concentrated sludge.

SUSTAINABILITY

Will Canada's forests continue to exist and to provide future generations with material, environmental, and social benefits in perpetuity? Sustainability of the forests involves more than the balance between harvest and growth, the growing of timber for Canadian and global markets. Spiritual and cultural forest values are important to many people. Our planet's biosphere and its forest ecosystems must be sustained.

Forestry in Canada is changing. And so is the planning approach to it. In the past, sustainability has meant sustainability of timber supply. It used as its indicators the balance between logging and growth and the age-class distribution of the trees (a steady supply of raw material to the mills depends on enough trees reaching cutting age each year). Today, new indicators are being developed that reflect a much broader view of the forest and incorporate both timber and nontimber values.

Today, with emphasis on forest ecosystem management and not just timber management, sustainability of the forests has a wider context than simply sustained yield. The issues and conflicts also become much more complex. Governments are now looking at how to manage to sustain the ecosystem as well as the economy. The provinces control 80% of the productive forest land and have responsibility for natural resources. Since the mid-1980s, most provinces have revised their forest policies, programs, and legislation. These changes are aimed at ensuring the regeneration of Canada's forests and that forestry concerns are fully integrated with wildlife and other resource and cultural concerns of the public.

Forestry Canada, created under the 1990 *Department of Forestry Act*, has as its mission "to promote the sustainable development and competitiveness of Canada's forest sector for the well-being of present and future generations of Canadians." The department has launched a major new forestry program under the Green Plan to promote the sustainable development of Canada's forests. The program will expand the data on Canada's forests, increase research, and establish a network of models of sustainable development in forestry.

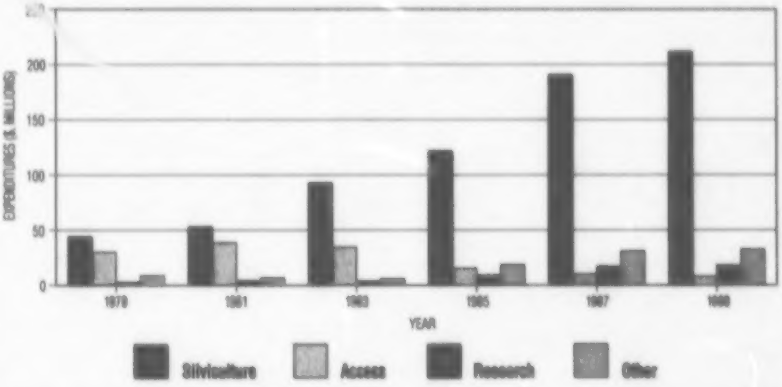
In 1987, the provincial and federal forestry ministers prepared a National Forest Sector Strategy for Canada. This strategy is now being revised to reflect Canadians' changing attitudes towards their forests and will be completed in 1992. The strategy, based on input from a broad range of interests and the public, will chart a direction to achieve sustainable development of Canada's forests. Figure 10.8 shows federal and provincial expenditures under forest agreements from 1979 to 1988.

Some sustainability questions involve more than forests and forestry. Pruitt (1989) has suggested that, given the possibility of major climatic change, a use of the boreal forest that might be more important than the economic returns on forest products may be simply to remain growing, as a carbon sink. The cultural sustainability of

FIGURE 10.8

Forestry expenditures, 1979–88

Federal and provincial expenditures on silviculture, roads, research, new product and market development, and protection (from fire and pests) under forest agreements, 1979–88.



Source: Forestry Canada and Canadian Pulp and Paper Association (1990).

native people who depend on hunting and fishing in forests that are not protected from resource development, including forestry, is another such question.

The market demand for Canada's forest products is, and will remain, strong. At the same time, the public's desire to protect the forest ecosystem and fight pollution is reflected in its participation in recycling programs and increased use of recycled paper (Box 10.5). The deep attachment of the public to Canada's forests and the public's interest in their management will continue to contribute to the health and sustainable development of Canada's forests for future generations.

BOX 10.5

Paper recycling

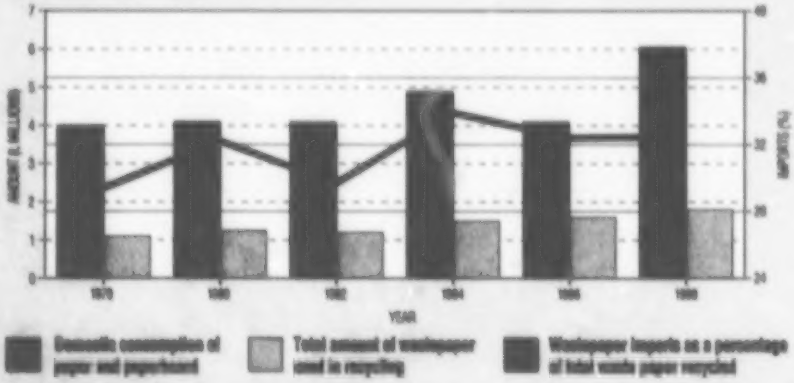
There is no evidence that recycling paper is reducing timber harvesting, but it is probably increasing supply. It certainly has the potential to save trees: 1 t of recycled paper provides the equivalent in paper products of 17–30 trees.

Wastepaper recycling has been practised by some Canadian paper mills for more than 60 years. Now 48 of Canada's 110 paper and paperboard mills are using wastepaper to meet all or part of their fibre requirements. In 1989, these mills consumed about 1.86 million tonnes of wastepaper. In the same year, Canadian mills produced in total 16.6 million tonnes of paper and paperboard products, more than two-thirds of which were exported, along with an additional 8.2 million tonnes of wood pulp. The majority of Canadian mills that recycle wastepaper are located near urban areas, where large quantities of wastepaper are generated. Even so, approximately one-third (554 000 t) of the total amount of wastepaper currently recycled is imported. It comes mainly from the United States. Figure 10.B1 shows the amount of paper used, and the amount recycled in Canada, from 1978 to 1988.

At present, there are six de-inking plants in Canada. Because of increasing demand for paper with a recycled content, particularly newsprint, a number of companies have announced expansions of existing de-inking facilities and construction of new de-inking plants. Not all coatings and inks can be removed from wood fibre economically, nor is de-inking environmentally benign. The effluent from the de-inking process is toxic to fish and must be treated before it is released into receiving waters. The sludge that results from wastewater treatment may contain harmful compounds, originating in some printing inks and in chemical agents used in the de-inking process.

FIGURE 10.B1

Wastepaper recycling, 1978–88



Source: Unpublished data from the Canadian Pulp and Paper Association.

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11

COURTESY OF I.B. MARSHALL, NEPEAN

HIGHLIGHTS

Canada is one of the world's principal exporters of minerals: 80% of domestic production is exported. The value of the export trade from the mining industry in 1990 was $18 billion.

■

Leaching of metals from tailings and waste rock into the aquatic environment is one of the most significant environmental concerns related to mining. Each year, about 650 million tonnes of wastes are added to the billions of tonnes of accumulated mining and mineral processing wastes.

■

Acid mine drainage, and its role in leaching metals, is one of the most serious environmental problems arising from the accumulation of mine wastes. Over 100 sites have actual or potential acid-generating wastes. Companies must treat tailings, waste rock, and effluents at operating sites and abandoned sites that they own to prevent or control acid mine drainage.

■

Based on the number of months that a mine was in compliance with the regulations, the 48 mines regulated under the federal Metal Mining Liquid Effluent Regulations met required effluent limits 84% of the time during 1986 and approximately 88% of the time in 1990.

■

The mining sector in Canada is the largest source of sulphur dioxide, a major contributor to acidic deposition. However, the sector's contribution to the national emissions total fell from 60% in 1970 to 50% in 1985 and is expected to decrease to about 37% after 1994, when the emissions targets of the Canadian sulphur dioxide control strategy are met.

■

Reclamation of abandoned mine sites remains a major long-term issue because of its high costs, the number of sites, and lack of technological solutions.

■

In Canada, about 50% of the iron, 55% of the lead, and 40% of the copper produced comes from recycled material. Recycling of metals generated over $2 billion in 1989.

■

Despite the lack of consistent information, the impacts from current mining and processing operations appear to be well managed at active sites through ongoing treatment and disposal methods.

■

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> **“Long-term economic growth depends upon a healthy environment and a healthy environment requires continued protection from excessive development. All industrial activity (including agriculture) produces some effect on the *biosphere* of the Earth, so the question of how much alteration to the environment is acceptable arises no matter what industry is involved. Mining is no exception.”**
>
> **— Northern Miner (1990)**

INTRODUCTION

The mining of minerals and metals and their incorporation in products for human use are ancient industries. The evolution from stone tools through to the manufacture of the automobile and the computer has been possible because of our human ability to act as prospector, metallurgist, and skilled craftsman.

The emergence of Canada as a world mineral and metal producer is relatively recent. Minerals and metals have been mined in Canada since early colonial days and have always been a major part of the extensive resource base that has made Canada prosperous. Today, mining is carried out in every province and territory of Canada.

Unfortunately, the large role that the mining, smelting, and refining of minerals and metals has played in the economic development of Canada has also left a legacy of pollution problems. This chapter focuses on the more serious environmental issues and shows how Canadian policies and programs are addressing these concerns. It identifies areas in which our knowledge base is insufficient to resolve the problems, then describes emerging technologies and changing attitudes that have the potential to improve the sustainability of mining and processing while protecting the environment.

THE MINERALS AND METALS SECTOR IN CANADA

More than 60 minerals and metals are mined, smelted, and refined in Canada, and many more are used in the manufacture of goods, construction, and other sectors of the economy (Fig. 11.1). Aluminum, copper, gravel, limestone, and cement are familiar parts of our daily lives. Materials like palladium and bismuth are less familiar but are nonetheless essential to a society based on high technology.

In 1990, over 500 producing mines were distributed across Canada (Table 11.1), more than half of which were large-volume extraction sites for structural materials (e.g., cement, sand, gravel, and crushed stone). Although mines frequently close and reopen in response to economic and other factors, the overall number of mines in Canada has not changed significantly in the last five years.

Economic significance

Mining, milling, smelting, and refining industries are major contributors to the Canadian economy, providing raw materials, exports, and jobs. Although we use mineral and metal products in all aspects of our daily lives, we are not always aware of the contributions this sector makes to regional development, the balance of payments from international trade, employment, and the transportation sector (see Box 11.1). In 1990, the value of Canadian mineral and metal production (excluding the production of oil and gas, which are dealt with in Chapter 12) was $19.7 billion, or 4.5% of the country's gross domestic product (Energy, Mines and Resources Canada 1991*a*). Of this total, metals like nickel, zinc, copper, gold, and iron contributed 60.6%. Energy-related minerals (e.g., coal and uranium) contributed 13.9%, structural minerals contributed 13.4%, and other nonmetals (e.g., potash, sulphur, salt, and asbestos) contributed 12.1%.

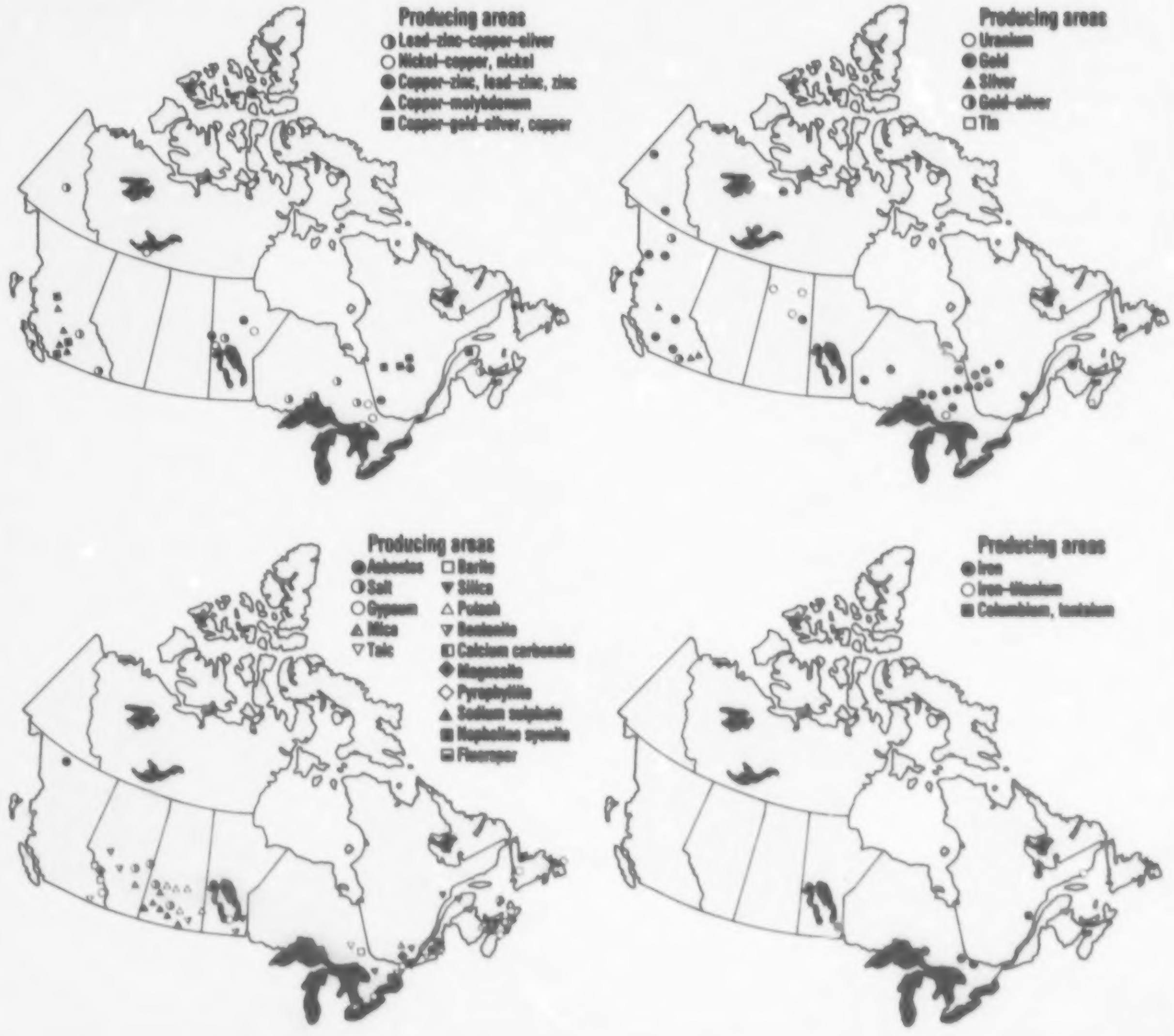
Mining can dominate the local economy. In 1986, mining activities made significant direct contributions to the local economies of an estimated 115 Canadian communities, whose combined population totalled approximately 1 million. In some areas, up to 80% of the labour force worked in the mining sector (Energy, Mines and Resources Canada 1990*a*).

The mining process

All rocks are composed of minerals. When a commercially attractive quantity of a mineral is discovered, however, the rock is called an ore. Often ores contain more than one mineral or metal of commercial interest. Gold, for example, is sometimes recovered in small quantities from mining operations for base metals, such as copper and zinc.

Figure 11.3

Principal mining areas of Canada, 1990


Producing areas
◑ Lead–zinc–copper–silver
○ Nickel–copper, nickel
● Copper–zinc, lead–zinc, zinc
▲ Copper–molybdenum
■ Copper–gold–silver, copper
Producing areas
○ Uranium
● Gold
▲ Silver
◑ Gold–silver
□ Tin
Producing areas
● Asbestos
◑ Salt
○ Gypsum
▲ Mica
▽ Talc
□ Barite
▼ Silica
△ Potash
▽ Bentonite
◧ Calcium carbonate
◆ Magnesite
◇ Pyrophyllite
▲ Sodium sulphate
■ Nepheline syenite
⊟ Fluorspar
Producing areas
● Iron
○ Iron–titanium
■ Columbium, tantalum

Source: Energy, Mines and Resources Canada (1990*c*).

Additional minerals in the ore in varieties or quantities that are not economically attractive are commonly discarded with the remaining rock residues.

The production of metals or minerals involves a number of phases, ranging from prospecting and exploration through extraction, milling, smelting, and refining.

Mineral exploration occurs all across Canada. In 1990, claims covering an area of 4 997 490 ha were recorded (exclusive of claims for coal) (Energy, Mines and Resources Canada 1991*c*). Although millions of hectares of land under various mineral leases and claims are temporarily subjected to some exploration activity (e.g., seismic lines, drilling, and trenches), only a fraction of this land is ultimately mined. Exploration activities are usually short in duration and sporadic in nature and, aside from occasional visual scarring of the landscape, result in little long-term damage to the environment.

An average of six to eight years elapses from the time a mineral deposit is discovered to the start of commercial production. The development stage

[illegible]

Producing mining establishments in Canada, as of January 1990[a]

Mineral group	Nfld.	N.S.	N.B.	Que.	Ont.	Man.	Sask.	Alta.	B.C.	Yukon	N.W.T.	Total
Metals	4	2	3	32	35	4	3	–	18	3	6	110
Nonmetals[b]												
Asbestos	1	–	–	2	–	–	–	–	1	–	–	4
Potash	–	–	2	–	–	–	10	–	–	–	–	12
All others	4	8	14	39	15	3	8	4	3	–	–	98
Structural materials[c]	6	11	8	108	92	11	2	20	19	–	–	277
Energy-related materials												
Uranium	–	–	–	–	2	–	3	–	–	–	–	5
Coal	–	3	1	–	–	–	5	11	8	–	–	28
Total	**15**	**24**	**28**	**181**	**144**	**18**	**31**	**35**	**49**	**3**	**6**	**534**

[a] There are only a limited number of small sand, gravel, and stone operations in Prince Edward Island.

[b] There are thousands more operations producing sand, gravel, and stone. Many other organizations that operate producing sand and gravel pits and stone quarries (including, for example, municipalities and construction companies) are in other industrial classifications and are not included in this table.

[c] Includes 55 peat operations: 33 in Quebec, 14 in New Brunswick, and 8 in six other provinces.

Source: R. Dunn, Energy, Mines and Resources Canada, Mineral and Metal Statistics Division, personal communication.

Box 11.1

Some economic statistics for the mining industry in the Canadian economy, 1990

- Canada is one of the world's largest exporters of minerals; 80% of domestic production is exported to other countries (65% to the United States).
- On a volume basis, Canada ranks first in the world in the production of uranium and zinc and second in the production of nickel, asbestos, gypsum, potash, and titanium. It is among the top five in the production of gold, copper, lead, and a number of other metals.
- The value of mineral and metal export trade from mining, smelting, and refining in 1990 was $18 billion. This was 12.8% of the total Canadian domestic exports in that year. When metal fabricated products are included, total export trade equals $25 billion, or 17.8% of total Canadian domestic exports.
- Copper, nickel, lead, zinc, gold, and iron accounted for 93% of the total value of all Canadian metal production in 1990.
- The industry employs over 150 000 people directly and 237 500 indirectly in metal fabricating industries dependent on minerals.
- The sector is a major user of Canada's transportation network. In 1989, crude and fabricated mineral products were responsible for 59% of all revenue freight transported by Canadian railways and 67% of the tonnage loaded at Canadian ports.

Source: Energy, Mines and Resources Canada (1990*a*, 1990*b*, 1991*a*, 1991*b*).

signals the start of the major disturbances that take place at a mine site, including the construction of roads and buildings, the sinking of mine shafts, and the stripping of surface vegetation and soil to form a working area. These changes may be very long-term or even permanent in nature, depending on the scale of the project, the characteristics of the mineral, and the methods of extraction used.

The way in which the mineral or metal occurs in nature determines the type of mining operation needed, the cost required to extract it, and the amount of waste produced in the process of extracting, separating, and concentrating it. In the case of sand and gravel extraction, very little material is discarded. In other cases, however, huge quantities of rock material and ore must be removed and discarded to obtain a relatively small amount of mineral or metal. For example, a typical copper grade of 2% will produce 20 kg of pure metal from each tonne of ore processed.

During the extraction stage, the mine is considered to be in production. Once the ore has been extracted, it is crushed and concentrated. These operations discard materials that are the source of some of the most significant environmental impacts of mining.

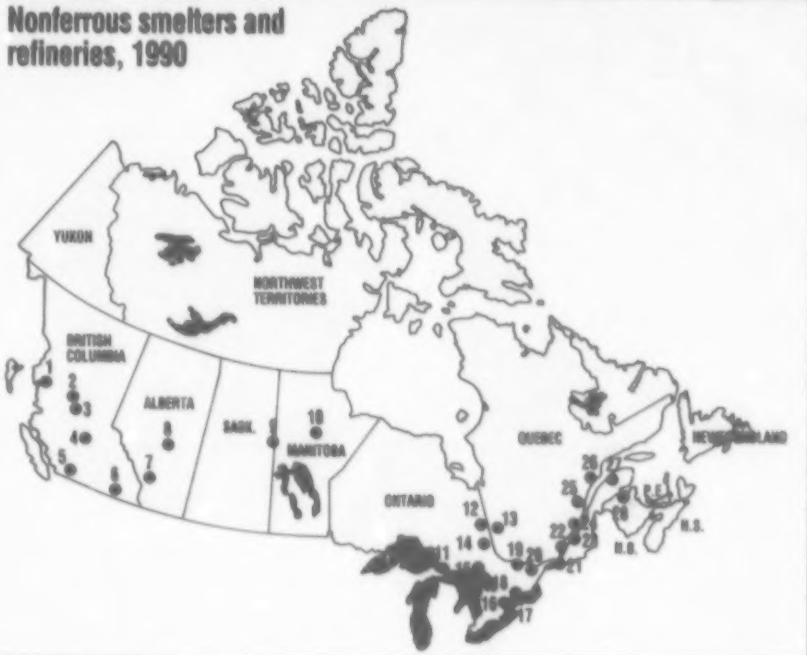
For many of the nonmetallic minerals and structural materials (e.g., sand, limestone, and gravel), basic processing is all that is needed before the substance is transported and used. Other nonmetallic minerals (e.g., asbestos, talc, and potash) require further processing before they are used or exported, and the metals, which constitute over half of Canada's mineral production, must be smelted or refined using high temperatures or chemical processes (see Fig. 11.2 for locations of major smelters and refineries in Canada). These processes can emit gases and particulate matter into the air unless these substances are captured by air pollution control equipment. The products of this stage are often formed into various shapes (e.g., ingots, bars, rods, sheets, etc.) prior to final manufacture of goods.

When the ore is depleted, the mine is closed, but steps must be taken to ensure that discarded materials are properly contained and monitored on an ongoing basis. The location and type of mine will dictate which processes are undertaken. Once the mine is closed permanently, legislation in most jurisdictions requires that the mine site be cleaned up and, if appropriate, reclaimed for other uses.

THE IMPACTS OF THE MINERALS AND METALS SECTOR ON THE ENVIRONMENT

Defining the significant environmental issues

It is difficult to draw firm conclusions about the overall contribution of this sector's activities to Canada's environmental problems. Canada lacks information about the extent and magnitude of environmental impacts caused by mining and processing of minerals; there are also insufficient data about industrial compliance with environmental regulations and guidelines. In addition, the industry faces many issues that are in fact the legacy of past practices. Although the environmental



Nonferrous smelters and refineries, 1990

1. **Kitimat:** Aluminum ingots and alloys
2. **Houston:** Ammonium dimolybdate, molybdic trioxide
3. **Endako:** Molybdic trioxide
4. **McLeese Lake:** Copper cathodes
5. **Port Coquitlam:** Tungsten, titanium, and tantalum–niobium (columbium) metal powders and carbides
6. **Trail:** Zinc, lead, silver, gold, cadmium, bismuth, tin, indium, germanium, antimonial lead, mercuric chloride, copper matte, sulphuric acid, ammonium sulphate, sulphur, liquid SO_2, high-purity metals
7. **High River:** Magnesium ingots and alloys
8. **Fort Saskatchewan:** Nickel, cobalt, copper sulphide, ammonium sulphate
9. **Flin Flon:** Copper anodes, zinc, cadmium
10. **Thompson:** Nickel, copper matte, precious metal residue, cobalt oxide
11. **Blind River:** Uranium trioxide
12. **Timmins:** Zinc, copper cathodes, cadmium, indium, sulphuric acid
13. **Noranda:** Copper anodes
14. **Cobalt:** Silver
15. **Falconbridge:** Nickel–copper matte
    Sudbury: Nickel oxide (sinter), nickel pellets and powder, nickel sulphate, copper (cathodes, wire bars), gold, silver, selenium, tellurium, platinum metals (in residues), sulphuric acid, liquid SO_2, sulphur
16. **Brampton:Toronto:** Gold, silver
17. **Port Colborne:** Utility nickel, nickel oxide, nickel–chromium–iron ingots, platinum metals (in residues), cobalt oxide, electrolytic cobalt
18. **Port Hope:** Uranium hexafluoride, uranium dioxide, uranium metals and alloys
19. **Haley:** Magnesium, magnesium alloy ingots, calcium, calcium alloys, strontium
20. **Ottawa:** Gold, silver
21. **Beauharnois:** Aluminum ingots and alloys
    Valleyfield: Zinc, cadmium, sulphuric acid
22. **Montreal-East:** Copper (cathodes, billets), gold, silver, tellurium, selenium, selenium salts, nickel sulphate, copper sulphate
23. **Sorel:** Titanium dioxide slag, iron
24. **Bécancour:** Aluminum ingots and alloys, magnesium ingots and alloys
25. **Grande Baie:** Aluminum ingots and alloys
    Isle Maligne: Aluminum ingots and alloys
    Jonquière: Aluminum ingots and alloys, alumina, aluminum chemicals, composite
26. **Baie Comeau:** Aluminum ingots and alloys
27. **Murdochville:** Copper anodes, sulphuric acid
28. **Belledune:** Lead, silver, copper matte, bismuth, sulphuric acid, antimony, diammonium phosphate

Source: Energy, Mines and Resources Canada (1990c).

performance of modern mining and processing industries is far better than that of companies that operated in the past, many industrial problems have no long-term, technical solution. These issues require additional research and development and large financial investments, so that all the known and potential environmental concerns can be understood and fully addressed.

Nevertheless, the nature and extent of many environmental problems related to the mining, smelting, and refining of minerals and metals in Canada today can be described, including:

- liquid effluent discharges containing metals and other contaminants;
- acid mine drainage from tailings disposal areas and waste rock piles;
- air emissions of sulphur dioxide, metals, and particulate matter; and
- finding long-term mitigation solutions to environmental problems at inactive, closed, and abandoned mine sites.

Water pollution

Most mine sites are now designed, as much as possible, to function as closed systems. Wastes are treated and stored on site, and untreated liquid effluents are released to the natural aquatic environment only when precipitation exceeds evaporation, when a faulty storage system leaks, or when human errors cause spills or other discharges. With modern mining practices, these events are infrequent.

The magnitude and complexity of water pollution problems originating from mining, milling, and further processing vary considerably from site to site (Blowes and Cherry 1991). Water pollutants can originate from three key sources: mine de-watering, liquid effluents from the milling process, and surface water drainage and seepage from waste storage areas and inactive mines. When the minerals are in the form of metal sulphides, mine water can become quite acidic. It can also contain the chemical residues from explosives used in blasting and oils and lubricants from drilling and extraction operations.

In the milling process, various reagents are used to extract the desired minerals from the ground ore. These reagents include cyanide, kerosene, organic flotation agents, activated carbon, and sulphuric acid. There are many possible combinations of processes and reagents tailored to treat the specific compositions of the ore being milled. Residual reagents can be found both in the liquid effluents from a mill and in the stored tailings.

During the milling process, ore is segregated from the waste rock. The ore is then crushed and ground finely to liberate as much of the desired mineral(s) as possible. The ground ore is then screened or subjected to physicochemical treatments such as gravity separation, flotation, or cyanidation to recover the desired mineral or metal. The product of this activity is the "concentrate." The remaining material comprises large quantities of finely ground rock particles that are discharged as a slurry of solids (tailings) in water and stored in a specially designed containment area (tailings pond) on the mine site. In most cases, all or part of the tailings and mine water is recirculated and reused in the mill.

The detailed design of treatment facilities and the choice of processes for the removal of metals and other substances from effluents also vary from mill to mill. The products of effluent treatment (called sludges) are generally stored with mill tailings in the tailings disposal area or may be transported and buried at a landfill site (Environment Canada 1987). Cyanide used in processing gold ore is often recovered and reused in the milling process. Other reagents, such as flotation agents used to recover base metals, are not recovered but adhere to the minerals in the concentrate or are discharged in the mill effluent to tailings ponds, where aeration, sedimentation, photodecomposition, and biological degradation combine over time to degrade many of the substances that might be harmful to the environment.

In some coastal operations, tailings have been discharged directly into the ocean, which has affected organisms living in the vicinity of the outfall (see Chapters 4 and 8) but has effectively prevented other impacts (e.g., from acid mine drainage).

The exact extent of liquid effluent discharges from the minerals and metals sector is difficult to estimate. Water discharge volumes may vary greatly at individual sites, depending on such factors as the characteristics of the ore being mined and milled, the overall availability of water in the region and its hydrological regime, the type of process used for extraction, and the overall production level of the site.

Metals

Sources and effects

Metals are present in sludges, tailings, waste rock, dusts, and gaseous emissions from smelting and refining. The escape into the environment of metals from these sources is one of the most significant environmental concerns for the mining industry. For example, metals leached from tailings and waste rock piles that generate acid drainage may escape into the receiving environment during snowmelt and periods of high rainfall (Errington and Ferguson 1987). Metals emitted from smelting are deposited in lakes and rivers, where they affect water quality and accumulate in sediments.

Metal contamination of lakes and rivers from mining activities occurs in most mining regions of Canada and has been studied in detail in the vicinity of smelters, such as near Sudbury, Flin Flon, and Rouyn-Noranda (Jackson 1978; Nriagu *et al.* 1982; Nriagu 1983; Carigan and Nriagu 1985; Arafat 1985; Allan 1987). Most of the extreme cases of water pollution are found near abandoned sites, as in the case of several mines in the Northwest Territories (Mudroch 1988).

Naturally occurring high levels of metals in waters and sediments in mining regions, which result from the natural weathering of rocks containing the metals, can be confused with industrial discharges. Often these high natural levels are discovered only once human activity gets under way at a given site.

Although minute quantities of many metals are essential to life, high concentrations can be harmful to many parts of the ecosystem, including zooplankton, phytoplankton, and, with high enough concentrations, fish and mammals (Canadian Council of Resource and Environment Ministers 1987) (see Chapters 3 and 4). Table 11.2 lists some examples of the toxic effects of metals on aquatic organisms.

Treatment and control

Mine effluents containing such metals as arsenic, cadmium, copper, iron, lead, nickel, and zinc are treated with lime to precipitate the dissolved metals in the form of hydroxides. Such treatment is generally effective at removing over 90% — in some cases, as much as 99% — of metals and suspended sediments from the mill effluent. In some instances, effluents discharged from tailings ponds must be treated further with lime to raise their pH and hence lower their metal content, before the water can be discharged to the natural receiving environment.

The sludge is commonly pumped back into the tailings pond. To avoid any leaching of harmful quantities of metals from the pond to the surrounding environment, the storage systems must be structurally stable and the sludge itself chemically stable (Environment Canada 1987).

Since the early 1970s, metal contamination at many mining sites has decreased, due to stricter regulatory controls and improved mining and processing practices. Noranda Minerals Inc. (1991), for example, has reported a 51% decrease in its metal discharges in effluents since 1985.

Controls are continuing to tighten. Under Ontario's Municipal/Industrial Strategy for Abatement, the province aims to virtually eliminate discharges of toxic substances to its receiving waters (see Chapter 14). A monitoring program for smelters has now been completed; it will be followed by the development of discharge regulations (Ontario Ministry of the Environment 1989, 1990*a*, 1990*b*). The requirement for industry to carry out testing of biological toxicity represents a clear departure from past effluent monitoring and regulation development practices and will provide a much-needed link between the chemical composition of effluents from the mining and mineral processing sector and their biological effects.

TABLE 11.2

Some toxic effects of selected metals on animals and plants, and water quality guidelines for the protection of aquatic life

Metal	Guideline	Notes on toxic effects
Aluminum	5 μg/L (<pH 6.5) 100 μg/L (>pH 6.5)	• Metal is most toxic between pH 4.4 and 5.4. • Metal can be acutely toxic to early stages of white suckers and salmon. • Invertebrates and amphibians are also susceptible to toxic effects.
Copper	2–6 μg/L, depending on water hardness	• Toxicity increases as water hardness and alkalinity decrease. • Plant growth may be inhibited. • Accumulates in algae and insects. • Early life stages of fish are more sensitive.
Lead	1–7 μg/L, depending on water hardness	• Acute toxicity is greater in soft water. • Amphipods are more sensitive than other aquatic species. • Metal can cause blackening of tail and spinal curvature in fish.
Mercury	0.2 μg/L	• Certain mercury compounds are extremely toxic to fish and man. • Plants are generally less sensitive than animals.
Nickel	25–150 μg/L, depending on water hardness	• Toxicity increases at lower water hardnesses and pHs and if copper is present. • Early life stages of fish are more sensitive than later stages.

Source: Canadian Council of Resource and Environment Ministers (1987).

Cyanide

Cyanide is widely used in the milling of gold and, to a far lesser extent, in base metal — e.g., copper, lead, and zinc — operations. The small quantity of cyanide used at base metal mills is not considered to pose an environmental problem, and the low concentrations present in effluents usually degrade naturally in the tailings ponds.

At gold mines, however, cyanide is used in higher concentrations. The cyanide and cyanide–metal compounds must be removed from the effluents, because natural degradation alone is inadequate to treat these wastes. Several effective alternative treatment methods have been devised, which either treat gold mill effluents directly or treat the water decanted from the tailings ponds in which natural degradation is occurring. These include the Inco sulphur dioxide–air process, the Noranda sulphur dioxide process, hydrogen peroxide, and biodegradation. With these technologies, cyanide removal can be over 95% effective (Environment Canada 1987). The cyanide, which is precipitated as a metallocyanide complex, generally ends up in the tailings pond. Liquid discharges to the environment also contain some cyanide, but significant impacts have not been reported.

Acid mine drainage

Mining companies have long been concerned with the acid-generating potential of tailings and waste rock dumps. Acid mine drainage was observed in 1698 in Pennsylvania coal mines, but the problem undoubtedly existed prior to this date (Paine 1987). Today, controlling acid mine drainage is still one of the industry's major environmental challenges.

Most of the base metals, precious metals (e.g., gold, silver, and platinum), and uranium found in Canada occur in association with sulphur. The ore from which the common metals are extracted, for example, may contain minerals composed of 13% to over 50% sulphur (Ripley *et al.* 1978). After the ore is processed, the sulphur-bearing minerals are discarded with the tailings and waste rock.

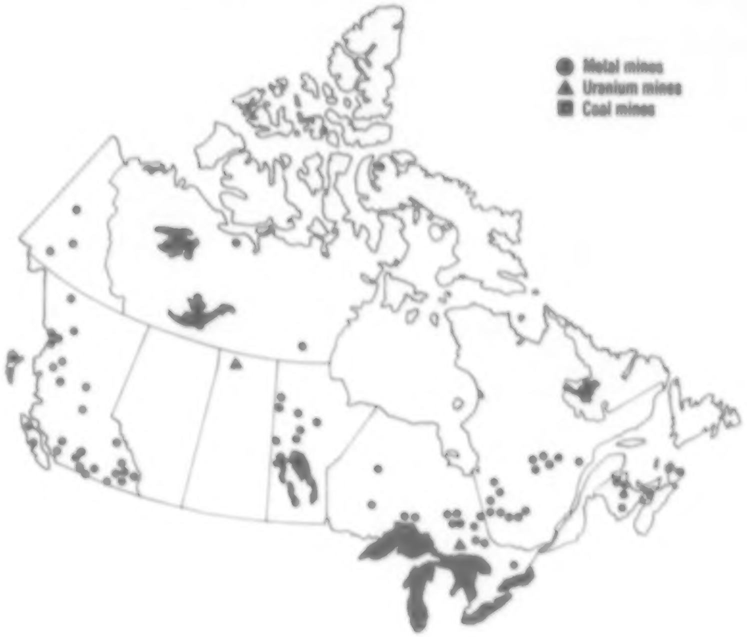
These metallic sulphide minerals react chemically and biologically with oxygen, moisture, and bacteria that use sulphur as a source of energy. The oxidation of the most reactive sulphide minerals, such as pyrite and pyrrhotite, can, in turn, cause the oxidation of other less reactive ones. Sulphuric acid is produced, which dissolves metals contained in the exposed rock and tailings. As the rate of the chemical reactions increases, so does the acidity and temperature of the milieu. Between pH 2 and 4, bacterial activity accelerates the chemical reactions 20–100 times (Knapp 1987). The presence of alkaline minerals in the rock matrix can prevent or slow down acid formation. However, if the acid-generating potential of the reactions exceeds the neutralizing capacity of the alkaline minerals, the rate of acid production will eventually increase.

Extent of the problem

There is no comprehensive inventory of all operating, temporarily closed, and abandoned acid-generating sites in Canada. However, two inventories of sulphide tailings and waste rock at base metal mines in Canada (Monenco Ltd. 1984; Nolan, Davis & Associates Ltd. 1987) estimated that the potential acid-generating sites stemming from base metal operations alone cover a land area of over 15 000 ha, an area larger than the city of Toronto. These inventories do not include some abandoned sites, uranium mining operations in Ontario (and, to a lesser extent, Saskatchewan), and coal mines in eastern Canada. (The western Canadian coal mines that produce 94% of the country's coal are, with one exception, not potential acid-generating sites.) The potential acid-generating areas of Canada are shown in Figure 11.3.

FIGURE 11.3

Acid mine drainage areas in Canada



Source: Monenco Ltd. (1984). Nolan, Davis & Associates Ltd. (1987).

Table 11.3 brings together information from several sources on the quantity of mining wastes that have the potential to cause acid mine drainage: approximately 315 million tonnes of waste rock and 511 million tonnes of tailings, stored at mine sites across the country. British Columbia has most of the waste rock, and Manitoba, Ontario, and Quebec house the largest accumulations of tailings. The following examples indicate the extent of acid mine drainage in different provinces:

- In Newfoundland and Labrador, 5 of 91 mine sites examined for possible negative environmental impacts had acid mine drainage potential (Golder Associates 1988).
- New Brunswick has eight metal mine sites, mostly concentrated in the Bathurst area, and N.B. Coal Limited has several acid mine drainage sites in the Minto area (Monenco Ltd. 1984; Nolan, Davis & Associates Ltd. 1987). Four rivers containing Atlantic salmon spawning grounds have been affected by acid mine drainage. If the mine sites were abandoned, acid would be generated for several hundred years, virtually eliminating the salmon fishery from those rivers (Intergovernmental Working Group on the Mineral Industry 1988).
- In Quebec, 33 of 103 mine sites, almost all located in the Abitibi–Témiskamingue region of northwestern Quebec, pose a potentially high risk to the environment and to human health. Some 93% of these high-risk sites have high potential to generate acid mine drainage. An additional 53 Quebec sites that pose medium and low risks to the environment also have the potential to generate acid (Ministère de l'Environnement du Québec 1990*a*, 1990*b*).
- In Ontario, 20 abandoned mine sites containing 55 million tonnes of acid-generating tailings cover an area

TABLE 11.3

Estimated tonnages of waste rock and sulphide tailings having the potential to cause acid mine drainage in Canada

Province/territory	Waste rock (t)	Sulphide tailings (t)	Other sources (t)
British Columbia	250 000 000	78 000 000	
Alberta	None		
Saskatchewan	None		Uranium sites
Manitoba	<100 000	126 400 000	
Ontario	50 000 000	91 600 000	24 750 000 (Elliot Lake inactive uranium sites)
Quebec	250 000	93 230 000	30 000 000 (gold)
New Brunswick	4 000 000	44 800 000	Coal (Minto)
Nova Scotia	None	Not given	Coal, gold, and Meguma slates
Newfoundland/Labrador	<100 000	Not given	Potential (gold)
Yukon	10 000 000	36 700 000	
Northwest Territories	<500 000	40 230 000	Some uranium sites
Total	**315 000 000**	**510 960 000**	**>54 750 000**

Note: These studies do not provide comprehensive inventories of all of the actual or potential acid mine drainage sites, as often the amounts of tailings or waste rock are based on estimates. Coal wastes in eastern Canada were not included.

Source: Melis (1983); Monenco Ltd. (1984); Nolan, Davis & Associates Ltd. (1987); Steffen Robertson and Kirsten Inc. (1987).

of about 830 ha (Filion *et al.* 1990). A similar number of sites, under the control of currently operating companies, are subject to ongoing treatment.

- In Manitoba, at least 13 sites have potential to generate acid; 7 of these sites contain significant tonnages of tailings (Monenco Ltd. 1984; Nolan, Davis & Associates Ltd. 1987).

- In Saskatchewan, approximately 360 000 t of uranium tailings were discharged directly into Nero Lake at the Lorado site between 1957 and 1960. This lake now has a pH of 2.3, and its water quality impacts on the water quality of at least one adjacent lake. The site also contains dry tailings that have considerable acid-generating potential (Intergovernmental Working Group on the Mineral Industry 1988).

- In British Columbia, one coal mine has the potential to generate acid. Five active and six abandoned metal mine sites contain acid-generating material (Errington and Ferguson 1987). Over 78 million tonnes of tailings and 250 million tonnes of waste rock at these metal mines are known to be generating acid mine drainage (Nolan, Davis & Associates Ltd. 1987).

- In the Yukon and the Northwest Territories, 11 sites containing sulphide wastes from base metal mines have acid-generating potential (Monenco Ltd. 1984; Nolan, Davis & Associates Ltd. 1987). The inactive uranium mine at Port Radium in the Northwest Territories is also generating acid (Melis 1983).

Acid generation is a problem for two reasons. First, the metals dissolved under acidic conditions can enter the aquatic environment, where they can be toxic to various organisms (see Table 11.2). Secondly, the acidity itself causes conditions that are toxic to organisms, especially fish (see Chapter 24), which have an optimal water pH range between 6.5 and 9.

The lag time for the onset of acid mine drainage may vary from one year to more than a decade, and acid may be generated for many years, causing more widespread environmental impacts. Low pH levels and high concentrations of such metals as copper and zinc have polluted British Columbia's receiving waters, causing elevated metal concentrations in bivalves, reducing fishing success, and changing plankton community structure (Errington and Ferguson 1987). Waste rock dumps at the abandoned Mount Washington site in British Columbia, for example, cover only a few hectares and yet release enough copper into the environment to eliminate salmon runs in the Tsolum River some 10 km away (Intergovernmental Working Group on the Mineral Industry 1988).

Control strategies

Treatment methods exist to neutralize acidic mine waters and to reduce the acid generation of tailings and waste rock. These methods involve ongoing expenditures and maintenance; none offers permanent, safe, "walk away" solutions. The potential for acid generation in the future, and the costs of managing the problem, are issues of great concern.

Operating mines that are currently creating acid mine drainage have all built neutralizing treatment plants. At a mine site near the Bulkley River in northern British Columbia, for example, uncontrolled effluent had the potential to destroy all the fish in the river. Therefore, Equity Silver Mines Ltd. is collecting and treating acid effluent at a cost of $1.5 million annually. Preventive treatment may be required for another century if no new technology is developed to permanently correct the problem (Intergovernmental Working Group on the Mineral Industry 1988).

Acid mine drainage is also a problem at abandoned mine sites. The cost of reclaiming the abandoned Kam Kotia site in Ontario, for example, which is a major source of acid, is estimated at between $12 and $20 million (Intergovernmental Working Group on the Mineral Industry 1988). The high costs of maintaining permanent treatment plants, and the lack of effective measures to permanently address acid mine drainage after a mine has closed, have led to a growing trend towards requiring the posting of performance bonds as part of the mine licensing procedure in some provinces.

Research into understanding, predicting, preventing, and mitigating the impacts from acid mine drainage has been carried out for many years. Much of it has focused on preventing oxygen from coming into contact with the sulphide tailings and waste rock. Early research indicated that revegetating waste rock and tailings could inhibit acid generation, but this does not work (Filion *et al.* 1990). For example, in the 1970s, Noranda Minerals Inc. revegetated the 40-ha Waite-Amulet tailings site in Quebec at a cost of $1.7 million. The revegetation program produced lush vegetation on the tailings surface, but seepage quality did not improve. The company has invested an additional $2.2 million in a lime treatment plant. Annual operating costs for the plant are about $500 000, and the tailings could generate acid for another 500 years (Intergovernmental Working Group on the Mineral Industry 1988).

Another example of the costs and difficulties is occurring in New Brunswick, where unstable thiosalts have formed sulphates only after their release to the environment (see Box 11.2).

BOX 11.2

Thiosalts: the search for a solution

About 20 years ago, Brunswick Mining and Smelting Corporation Limited began discharging mine water and mill effluents containing residues of metals, acids, and other contaminants into the Little River in New Brunswick. Fish and other aquatic life were affected directly until the company built a settling pond and began treating its wastes with lime. When it left the mine site the water was quite alkaline, and it appeared that the environmental problems in the river were being addressed.

During the warm periods of the year, however, the stream from the mill and parts of the river became toxic to aquatic life as a result of high acidity (Brunswick Mining and Smelting Corporation Ltd. 1989). Investigations revealed that the mill discharge contained unstable thiosalts that were unaffected by lime treatment. Thiosalts are partially oxidized sulphur compounds that are formed when sulphide ores are milled. They are less likely to form in acidic to weakly alkaline media, and they require very little dissolved oxygen for their formation (Rolia and Tan 1985). Thiosalts tend to oxidize when released to the environment, forming sulphates and releasing acid. As the thiosalts travelled slowly down the well-aerated stream, they were oxidized to sulphuric acid, affecting water quality and aquatic life in the river.

The company has spent over 10 years trying to resolve the thiosalt problem. Of the dozens of potential solutions examined, only a few have shown promise. None actually solves the problem, and all are very expensive. One of the techniques used by Brunswick Mining and Smelting is the addition of bacterial agents to a large pond to break down thiosalts. These bacteria can remove nearly 90% of the thiosalts during the summer, but the success rate drops to less than 10% in the winter. Another technique would require the construction of a huge shallow pond (30 km long and over 200 m wide). The wastewater would be retained for two years, at a cost of $4.1 million per year, while bacteria attacked the thiosalts. Other techniques are even more expensive and include full-scale biological air oxidation systems, additions of chemicals (such as hydrogen peroxide), and pumping wastewater over long distances to the sea.

New techniques to inhibit acid formation are under investigation; these include the use of impermeable covers and the disposal of tailings and waste rock under water. In Canada, several recent programs have made considerable progress in understanding and dealing with the issue. The Government of Canada's five-year National Uranium Tailings Program, initiated in 1982, led to the Reactive Acid Tailings Stabilization program, which evolved, in 1988, into the Mine Environment Neutral Drainage Program, an industry-initiated, joint federal/provincial/ industry, five-year national research program aimed at developing effective and permanent techniques for dealing with acid mine drainage. At about the same time, British Columbia established its Acid Mine Drainage Task Force. The Task Force projects are funded by industry and the federal and provincial governments, and research sponsored under the Task Force is coordinated with the national program. Both programs focus on prediction (e.g., modelling of reactive tailings), prevention, treatment, and control (e.g., flooding of tailings sites, blending and segregation of waste rock), and monitoring (e.g., sediment monitoring) (Filion *et al.* 1990). Ontario and Quebec are developing similar programs.

Saline mine drainage

Saline mine drainage is associated mainly with the production of potash in Saskatchewan and New Brunswick. Potash mines annually produce millions of tonnes of tailings composed of sodium chloride, potassium chloride, clay, gypsum, and dolomite, in addition to liquid effluent brines.

In Saskatchewan, potash tailings are piled on the surface to form mounds; to date, 300 million tonnes of tailings have been deposited by 10 mines over a 5 000-ha area (Environment Canada 1984; Fredlund and Mittal 1989; Hart 1989; Saskatchewan Department of Environment and Public Safety 1991). In New Brunswick, tailings are backfilled into mine cavities or dissolved and pumped into the Bay of Fundy. Liquid effluent brines are stored initially in ditches, then injected into brine disposal wells leading to saline aquifers or pumped directly into the ocean.

Both the tailings and brine have the potential to contaminate surface water and groundwater through saline drainage runoff and seepage. Wind may also transport and deposit salts onto surrounding land. These particulate emissions, as well as the visual impact of the tailings piles, are growing concerns. None of the mines has exceeded provincial air emission guidelines, although local residents complain of accelerated rusting and localized tree damage (Saskatchewan Department of Environment and Public Safety 1991).

Saline drainage does not appear to be causing any major environmental damage at present. The potash industry is implementing control measures to meet provincial regulations, and the mines have caused few impacts beyond the mine site. However, no long-term management solutions or reclamation techniques exist. Hart (1989) projected that if Canada continues to be a world leader in potash production, between 14 and 28 billion tonnes of salt wastes (tailings, brines, and slimes), covering between 80 000 and 160 000 ha, could accumulate by the middle of the next century. The long-term problem, therefore, centres around how to manage the accumulating waste, the lack of long-term tailings and brine management solutions, and the cost of ensuring that scarce water resources, particularly in Saskatchewan, are not contaminated with salt.

A recently announced joint federal/provincial/industry research program will spend $8 million over five years on issues related to competitiveness, productivity, and environmental protection in the Saskatchewan potash industry. The environmental component of the program will concentrate on developing waste management practices and technologies that provide long-term environmental protection. For example, in its first year, research will focus on ways to keep salt tailings from dissolving and spreading from the tailings disposal areas (G. Feasby, Energy, Mines and Resources Canada, Mineral and Energy Technology Sector, personal communication).

Radionuclides

Uranium is or has been mined in Ontario, northern Saskatchewan, and the Northwest Territories. As with metal mining in general, uranium tailings that contain iron sulphide may generate acid mine drainage. Many of the mine sites in the Elliot Lake area of Ontario and a few sites in Saskatchewan and the Northwest Territories are generating acid.

About 185 million tonnes of tailings have been produced from Canada's uranium mines (Melis 1983; C. Letourneau, Energy, Mines and Resources Canada, Radioactive Waste and Radiation Division, personal communication) and are stored at 17 inactive and 5 active mines. In addition to acid precursors and heavy metals, uranium tailings also contain a variety of radioactive species of atoms, or radionuclides, including radium-226, thorium-230, lead-210, and polonium-210. The radionuclides are products of the natural decay of uranium and are not extracted during the milling process.

Some of these radionuclides have long half-lives. Thorium-230, for example, has a half-life of about 80 000 years, which means that radioactivity from thorium will persist in the tailings for hundreds of thousands of years (Steffen Robertson and Kirsten Inc. 1987). The pH of the tailings plays a significant role in determining how soluble some of these radionuclides become. Thorium, in particular, becomes more available when the pH drops below 4 (Constable and Snodgrass 1987).

Although radionuclides occur naturally at low concentrations in rocks and soils, concentrations in uranium tailings are high enough for them to be considered low-level radioactive wastes. Uranium mine tailings and effluents therefore require special storage, although the level of radioactivity is not high enough to warrant radiation shielding during handling and storage.

The main exposure pathways for radioactivity from tailings are direct gamma radiation, inhalation of radioactive particulates, and ingestion of radionuclides through the food chain. The National Uranium Tailings Program concluded that the radioactivity from tailings sources is not likely to expose humans to any undue risks. In fact, it concluded that other environmental contaminants in the tailings, such as metals and acid drainage, were of greater concern. A mathematical model, developed as part of this program, enables researchers to predict the long-term effects of uranium tailings (Senes Consultants Ltd. 1984, 1985, 1986). Another mathematical model for assessing the risk from uranium tailings piles over a 1000-year period has also been developed by Murray *et al.* (1987).[1]

There is still concern about the fate of radionuclides in the environment, but some progress has been made in cleaning up past pollution. In Ontario, for example, serious pollution of the Serpent River basin from uranium mines in the Elliot Lake area was reported in the 1960s. Radium-226, for instance, was recorded at 50–200 times the background levels in certain lakes. The radium was removed from the effluent using barium chloride, and new containment dams were constructed with impermeable synthetic or clay cores to prevent seepage. This virtually restored the Serpent River system, and the area is now being restocked with fish (John 1987).

The Atomic Energy Control Board is responsible under the federal *Atomic Energy Control Act* for closely regulating the development, operation, closure, and site decommissioning of uranium mines and mills. The federal Metal Mining Liquid Effluent Regulations (see Box 11.3) apply to radium-226 and metal contaminants that may be present in uranium mill effluents. The Atomic Energy Control Board cooperates with Environment Canada, the Department of Fisheries and Oceans, and provincial agencies in regulating new facilities. Saskatchewan has drafted regulations for uranium mines and has added more stringent reclamation and cleanup requirements as part of the conditions of leasing Crown land.

The Beaverlodge (Saskatchewan) and Agnew Lake and Faraday (Ontario) uranium mines are currently at advanced stages of decommissioning. The mine closure and site decommissioning plans now require environmental monitoring. For example,

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[1] For information on the effects of radiation exposure on plants, animals, and humans, consult the International Atomic Energy Agency/World Health Organization (1982) and Murray (1983).

BOX 11.3

The federal Metal Mining Liquid Effluent Regulations and guidelines

Environment Canada administers the provisions of the *Fisheries Act* pertaining to effluents, and the Department of Fisheries and Oceans deals with the protection of fish habitat. The federal government issued the Metal Mining Liquid Effluent Regulations in 1977 under the *Fisheries Act*, because mining wastes have their greatest impacts on aquatic ecosystems. The regulations limit the concentrations of arsenic, copper, lead, nickel, zinc, total suspended matter, and radium-226 in mining effluents, as well as regulate pH. A separate guideline measures the acute toxicity of liquid effluents from metal mines.

The regulations exclude gold mining operations using cyanidation processes (exempted because, at the time of regulation development, no practicable treatment methods were available to enable companies to remove cyanide and metal cyanide complexes from gold mine effluents), as well as metal mines that were operating before 1977. Mines/mills operating prior to this date are encouraged to comply with voluntary guidelines that contain the same limits as the regulations. The general provisions of the *Fisheries Act* (which prohibit the discharge of deleterious materials into fish-bearing waters) still apply to mines under the guidelines. In 1990, 48 mines were subject to the regulations, and another 54 were subject to the guidelines (L. Surges, Environment Canada, personal communication).

The federal and provincial governments cooperate in implementing the federal regulations. In most provinces, provincial permits are usually consistent with the federal regulations (some may have lower limits or include additional parameters). In the provinces and territories where metal mining takes place, the companies do most of the monitoring of the mine effluents. Where provincial/territorial regulations are more stringent than federal regulations, the more stringent limit prevails. In British Columbia, many permits are based on dissolved metals rather than total metals, as is the requirement in the federal regulations. However, there is an increasing trend towards including a total metals requirement, which is consistent with the regulations. In the case of uranium mines, the regulation limits are included in the licences issued by the Atomic Energy Control Board of Canada.

The frequency with which a mine's effluents meet the limits prescribed in the regulations is determined on the basis of the monthly arithmetic mean concentration. Based on the number of months that a mine was in compliance with the regulations, the regulated mines met all the required effluent limits 84% of the time during 1986 (Environment Canada 1988) and approximately 88% of the time in 1990 (L. Surges, Environment Canada, personal communication). The Mining Association of Canada is concerned about the compliance of the industry with the federal regulations and has urged its members to improve their performance.

The federal government's Green Plan indicates that new regulations and controls for effluents, emissions, and other discarded material will be developed for metal mines (Government of Canada 1990). Reports outlining control options on which to base the regulations are to be ready by 1994.

Beaverlodge has been monitored for six years, and the company is preparing an application to return the property to the Saskatchewan government. The procedures now in place will ensure that the environment is not damaged over the long term and that the government is no longer responsible for liabilities from abandoned sites. The decommissioning and reclamation of the Quirke and Panel mines (Ontario) are now under review.

Air pollution

The smelters and iron blast furnaces used by the mining industry require high operating temperatures and emit various pollutants: particulate matter, nitrogen oxides, sulphur dioxide, vaporized metals, and volatile organic compounds. All may be deposited locally or transported over long distances.

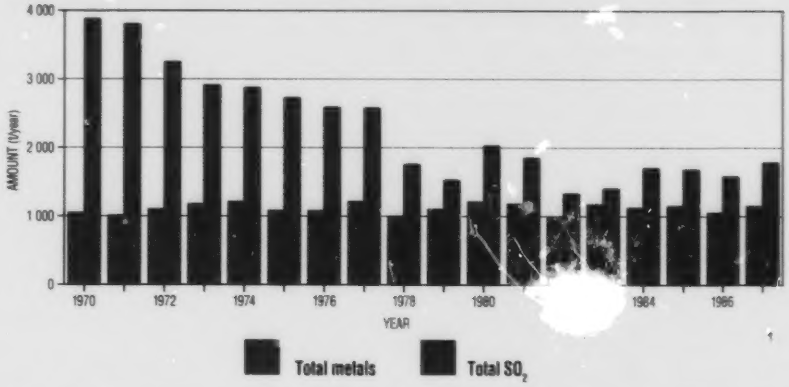
Sulphur dioxide

The best-known emission from smelters is sulphur dioxide. In the past, Canadian smelters emitted large volumes of sulphur dioxide directly into the atmosphere. The industry has been steadily improving its processes over the past 50 years. Just a few decades ago, uncontrolled releases of sulphur dioxide from smelters completely destroyed vegetation in some areas. Emissions have been much reduced in recent years (Fig. 11.4), but the potential for continued damage exists (Lynch-Stewart *et al.* 1987; Federal/Provincial Research and Monitoring Coordinating Committee 1990*b*). Human health can also be adversely affected — particularly the lungs (Hilborn and Still 1990). But perhaps the best-known effect of sulphur dioxide on the environment is its major contribution to acid rain, which acidifies lakes, rivers, and soils and can adversely affect aquatic life, forests, and vegetation (Hélie and Wickware 1990; Hilborn and Still 1990) (see Chapter 24).

The minerals and metals sector remains the largest single source of sulphur dioxide emissions in Canada. Between 1970 and 1985, however, it significantly decreased its overall contribution from 60% to 50% of the national emissions total for all sources of sulphur dioxide (Environment Canada 1986*b*; Kosteltz and Deslauriers 1990). This contribution is expected to decrease to about 37% after 1994, when the emissions targets of the Canadian sulphur dioxide control strategy are met (Federal/Provincial Research and Monitoring Coordinating Committee 1990*a*; see Chapter 24 for details). Table 11.4 shows actual sulphur dioxide emissions from primary metals industry sources from 1980 to 1987 in eastern Canada, together with a projection for 1994. The decreasing trend in emissions of sulphur dioxide per tonne of metal produced at these smelters is shown in Table 11.5.

FIGURE 11.4

Metal production and sulphur dioxide emissions from the eastern Canadian nonferrous smelting sector, 1970–87



Source: Paine (1989).

TABLE 11.4

Eastern Canada sulphur dioxide emissions and projections from primary metal smelting

	Emissions (kt)			
Province	**1980**	**1985**	**1987**	**1994**[a]
New Brunswick	13	17	21	21
Quebec	641	502	463	311
Ontario	1 031	899	816	461
Manitoba	463	459	539	440
Total	**2 148**	**1 877**	**1 839**	**1 233**

[a] Projected.

Source: Federal/Provincial Research and Monitoring Coordinating Committee (1990*a*).

The smelters participating in the Canadian sulphur dioxide control strategy are meeting or exceeding the emissions targets. They have implemented a variety of measures to meet the emissions targets: rejecting ores with higher sulphur contents (e.g., Inco Ltd., Manitoba), recovering the emissions to produce sulphuric acid as a commercial by-product (e.g., Inco Ltd., Ontario; Noranda Minerals Inc., Quebec), flash smelting of bulk copper and nickel concentrates (e.g., Inco Ltd., Ontario), and full plant modernizations that increase overall extraction efficiency. Capital investments to meet the 1994 targets range from $30 million at some plant sites to $494 million at others, depending on the approach used (Federal/Provincial Research and Monitoring Coordinating Committee 1990*a*).

Metals

Smelting and refining processes emit metals into the atmosphere; although the industry is a major source of such emissions, little recent inventory information exists. A preliminary report using 1982 data (Fig. 11.5) shows that copper/nickel production accounted for the largest percentage of national air emissions of arsenic, cadmium, nickel, and copper, whereas lead/zinc production contributed the largest percentage of the antimony and mercury emissions. However, these figures do not reflect changes in smelting technology used in Canada during the past decade. Changes in technologies, plant modernizations, and an interest in metal recycling and recovery have combined to decrease the volume of metals emitted into the atmosphere. In some cases, initiatives that are part of the industry's sulphur dioxide reduction strategy also result in reduced metal emissions. At Noranda Minerals Inc. (1991), the installation of the sulphuric acid plant at its copper smelter in Rouyn-Noranda resulted in an estimated 65% decrease in metal discharges from 1985 to 1990.

In 1985, Fenco Engineers Inc. summarized heavy metal emissions from eight smelters across Canada in the late 1970s and early 1980s. Soils had been heavily contaminated with metals within 3 km of each smelter, and these soils were toxic to plants. In the Sudbury and Flin Flon areas, high concentrations of metals were found in the surface waters, sediments, plankton, aquatic plants, and fish. In areas near Rouyn-Noranda, Quebec, and Yellowknife, Northwest Territories, metal concentrations in the bottom sediments of lakes also exceeded background levels (Allan 1987). In 1988, Noranda Minerals Inc. found elevated lead concentrations around Murdochville and Rouyn-Noranda. Although the concentrations were below regulated limits, Noranda initiated a voluntary soil removal and replacement program for the affected area.

Although the operating companies associated with these studies have taken action to decrease their metal emissions, the residuals from past emissions remain in the sediments of lakes and rivers, where they can be transported, affecting plants and animals in other areas. Most of the work carried out on metals in bottom sediments and other ecosystem compartments was conducted before 1982; little is known of the current status of metal contamination and potential long-term impacts on ecosystems.

TABLE 11.5

Sulphur dioxide emissions (kilotonnes) per kilotonne of metal production at selected smelters in eastern Canada

Smelter/location	Product	SO_2 emissions (kt/kt metal production)		
		1970	1980	1987
Hudson Bay Mining & Smelting, Flin Flon, Manitoba[a]	Copper, zinc	2.24	1.83	2.11
Inco Ltd., Thompson, Ontario	Nickel, copper	7.71	5.06	3.95
Inco Ltd., Sudbury, Ontario	Copper, nickel	4.92	2.38	2.12
Falconbridge Ltd., Falconbridge, Ontario	Nickel, copper	7.28	2.30	1.65
Falconbridge Ltd., Kidd Creek Division, Timmins, Ontario	Copper, zinc	n/a	0.01	0.02
Canadian Electrolytic Zinc (Noranda), Valleyfield, Quebec	Zinc	0.02	0.03	0.02
Noranda Minerals Inc., Rouyn-Noranda, Quebec	Copper	3.24	2.75	2.73
Noranda Minerals Inc., Murdochville, Quebec	Copper	2.44	1.44	0.83
Brunswick Mining and Smelting Ltd., Belledune, New Brunswick[b]	Zinc, lead	0.37	0.29	0.27

n/a = not available

[a] The increase in SO_2 per kilotonne of metal production from 1980 to 1987 is attributable to variability in the sulphur content of concentrates handled at this custom smelter.

[b] Since 1971, solely a lead-producing smelter.

Source: Adapted from Federal/Provincial Research and Monitoring Coordinating Committee (1990*a*).

Dust from tailings

Tailings ponds allow solids to settle out so that process water can be decanted off. As the surface of the tailings dries, it is subjected to wind erosion, particularly during dry periods of the year. Materials have been transported up to 50 km. The mining industry controls dust by spraying the surface of tailings with latex sealants or water, by maintaining a water cover, and by revegetating areas that are no longer used. Environment Canada (1986*b*) estimated that 63 000 t of particulate emissions originated from tailings in 1980. Such dusts not only are a nuisance but also may directly affect environmental and human health, depending on the composition of the tailings and mitigation procedures in place.

Some minerals have received more scrutiny than others. Asbestos tailings, for example, covered over 2 500 ha of Quebec in 1977 (Ministère de l'Environnement du Québec 1988). Wind erosion of the tailings piles is controlled by using moisture and revegetation methods tailored to both the composition of the tailings and the configuration of the piles. Nonetheless, Environment Canada (Sebastien *et al.* 1986) found the levels of asbestos fibres in the air of a Quebec mining region to be 10–1 000 times higher than urban background levels. Although prolonged occupational exposure to asbestos dust has been linked to forms of lung cancer, epidemiological studies of the region's residents have not been able to determine the health effects resulting from exposure to asbestos fibres at these levels. The presence of asbestos fibres in rivers near tailings disposal areas is not considered to be a problem from either human health or environmental points of view (Ministère de l'Environnement du Québec 1990*b*).

Abandoned mine sites

Abandoned mines pose many potentially serious problems, from acid mine drainage to contamination by metals and radionuclides. Even sites that harbour no harmful materials, such as abandoned gravel pits and quarries, may still permanently alter the way in which the land can be used in the future.

Most mines that are now abandoned were operated according to prevailing environmental norms, which were quite different from those of today. However, the mine owners retain the responsibility for rehabilitating them. If the mine operators cannot be identified or if the title has reverted to the Crown, federal and provincial governments must assume the responsibility and the often high costs of rehabilitating these sites.

Environmental impact

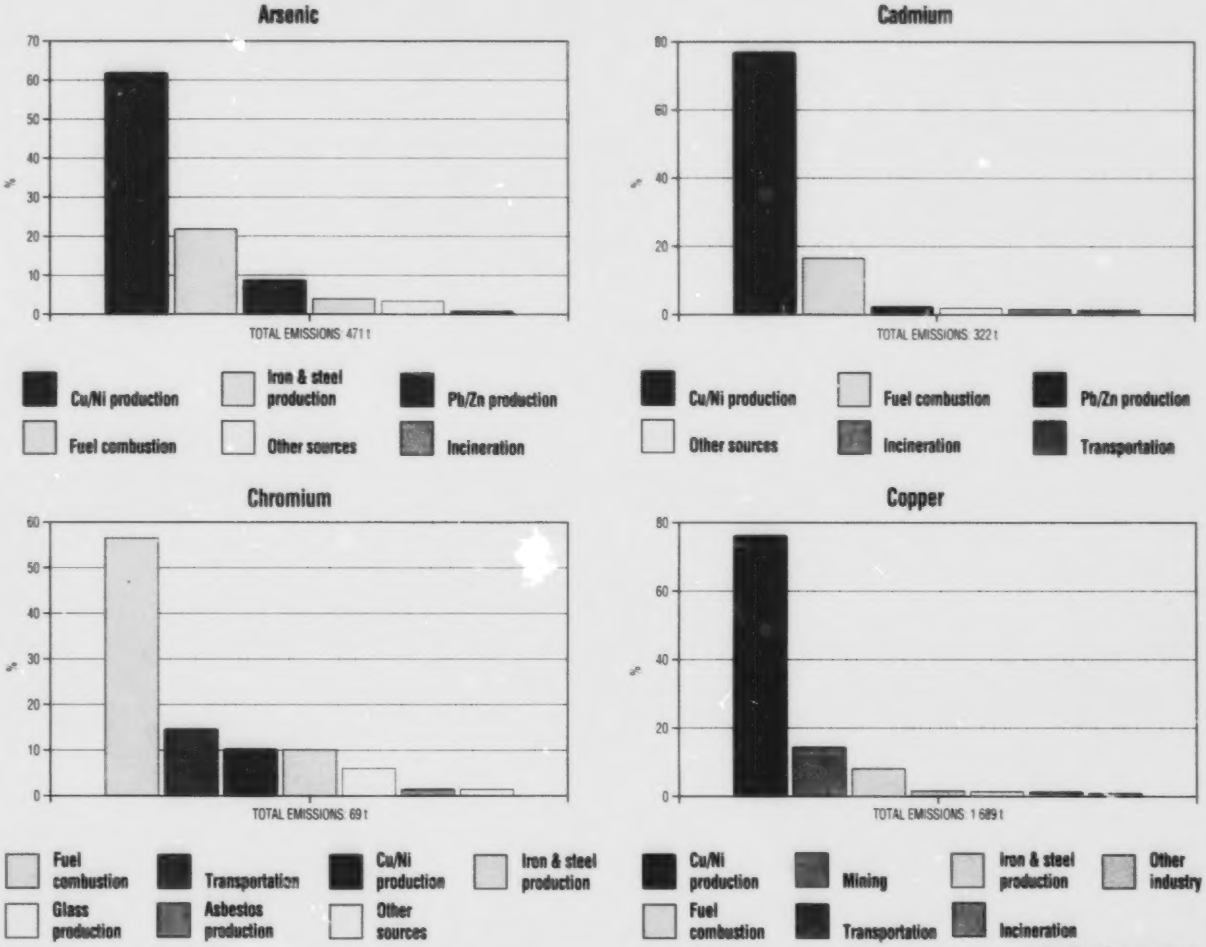
The exact number of abandoned mines in Canada is unknown, but the Canadian Shield area of Ontario and Quebec probably contains the greatest concentration. The Ontario Ministry of Northern Development and Mines "Geoscience" database identifies 5 780 mines in the province (excluding mineral aggregate pits and quarries), less than 5% of which are still active. About 90% of the abandoned mines were gold mines. Overall, fewer than 50 sites are known to have acid drainage problems.

In Saskatchewan, about 550 mines were abandoned before 1980, when regulations for decommissioning were established and reclamation standards set. Most of the mines were small and needed little corrective action. However, the province has identified 30 sites that may require further work under its Abandoned Mines Program (Saskatchewan Department of Environment and Public Safety 1991).

Hundreds of abandoned mines are scattered throughout the Atlantic provinces. At least 207 mostly abandoned sites in Nova Scotia and 12 in New Brunswick have the potential to contaminate groundwater resources (Nolan, Davis & Associates Ltd. 1987). Many of the Nova Scotia sites are abandoned gold mines, which can pose serious dangers. For example, Mudroch and Clair (1986) described arsenic and mercury contamination in the sediments and water of the Shubenacadie River headwaters from an abandoned gold mine. About 17% of the wells sampled in the area were contaminated with arsenic, and arsenic, mercury,

FIGURE 11.5

Heavy metal emissions in Canada



(Continued on next page)

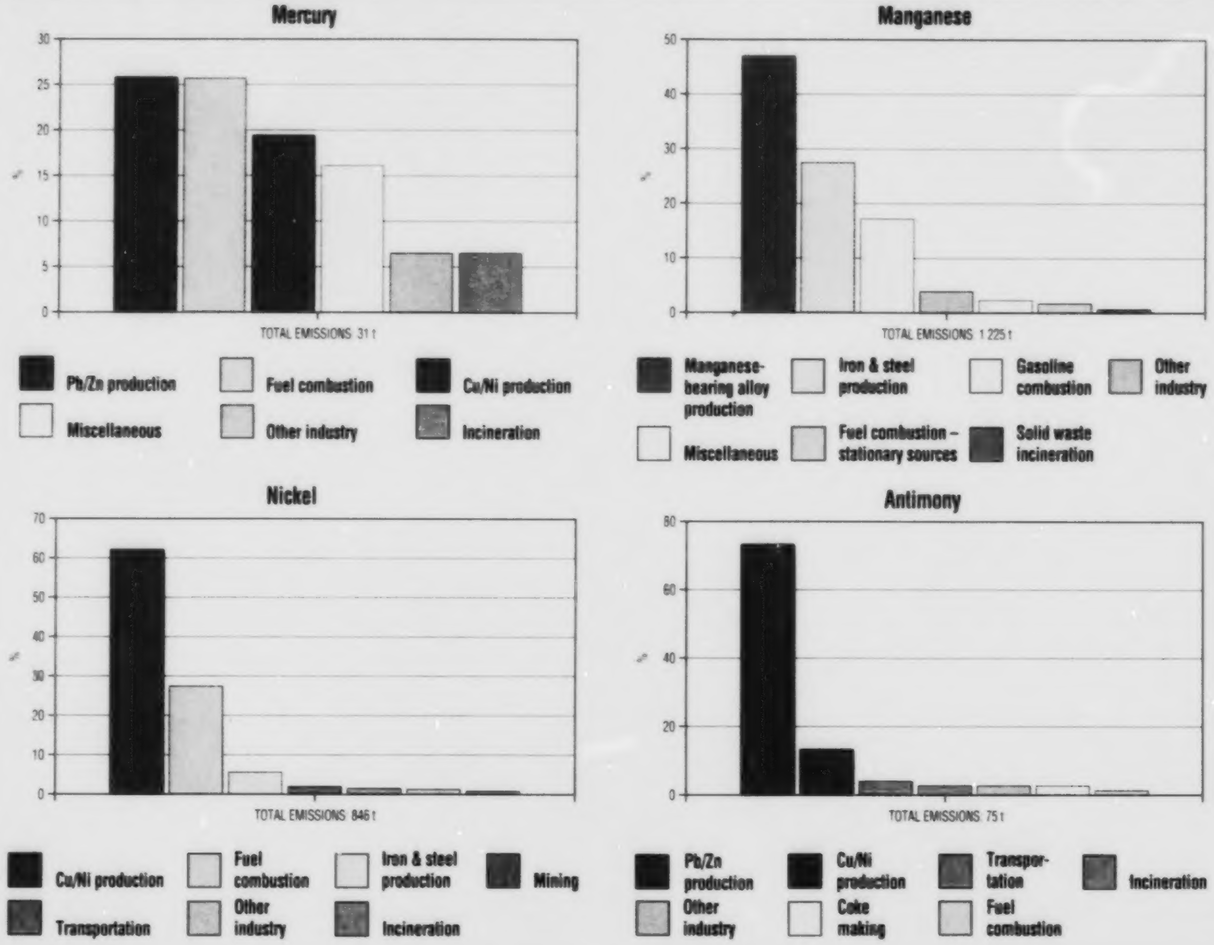
lead, and zinc were discovered in lakes downstream from the abandoned mine.

In the Northwest Territories, several abandoned mines are causing environmental problems. Tailings from the Discovery gold mine, for example, which operated between 1950 and 1969, were contaminated with mercury, which affected fish in adjacent lakes. The tailings were also acid generating, and levels of lead, zinc, nickel, arsenic, and mercury are still high near the Discovery mine site (Hall and Sutherland 1988). The Rayrock uranium mine, which operated between 1957 and 1959, produced about 80 000 t of tailings; these tailings are both acid generating and more highly contaminated with radionuclides than other uranium tailings in Canada. Lakes adjacent to this site are still contaminated. In both cases, reclamation was not carried out when the mine was closed.

Not only does Canada lack an accurate inventory of abandoned mine sites; the quantity of waste material stored at the country's estimated 6 000 abandoned tailings sites is unknown, and their potential hazard to the environment has not been assessed (Intergovernmental Working Group on the Mineral Industry 1991). Even in cases in which the quantity and nature of the waste are relatively well known, its damage-causing potential may be difficult to gauge. Problems may occur only after unpredictable time lags and may emerge in an area far removed from the mine. For example, a clue that a problem exists may appear in a component of an ecosystem, such as the accumulation of a metal in the tissue of fish distant from the site.

An additional hazard at abandoned sites is potential structural failures, such as

FIGURE 11.5 (CONT'D)



Source: Jaques and Kosteltz (1988).

the recent failure of the tailings dam near Matachewan, Ontario (Intergovernmental Working Group on the Mineral Industry 1991). In the fall of 1991, more than 100 000 m^3 of tailings slurry slid into Davidson Creek, which flows into the Montreal River. Within a week, a plume of particulate material had travelled over 100 km down the river to Lake Timiskaming.

Government action

Despite the lack of detailed inventories on the numbers of abandoned mines and on the nature and extent of environmental problems these sites might pose, governments have enough evidence to target the most serious cases. Ontario, for example, is developing an abandoned mine cleanup program. Detailed studies of Timmins, Cobalt, Kirkland Lake, and other mining communities have been conducted, and strategies to clean up sites are being considered (H. Rabski, Ontario Ministry of Northern Development and Mines, personal communication).

Provincial governments are amending their regulatory and licensing procedures to ensure that operators are held fully responsible for the closure and rehabilitation of their mines. Requirements include attaching specific conditions for permanent mine closure in permit approvals, setting specific land reclamation and site decommissioning objectives, and requiring companies to post bonds or security deposits to ensure that reclamation is completed or, failing an acceptable reclamation solution, to ensure the continued safe management of the site (see Box 11.4 for reclamation programs in Alberta).

The government of British Columbia, for example, which had to spend over $500 000 in 1988 to treat acid-generating waste rock at the abandoned Mount Washington mine, now requires companies to post multimillion-dollar bonds as part of the mine approval process, to cover any long-term post-closure problems. In the Yukon, a

BOX 11.4

Reclamation programs: Alberta case study

Alberta has the most active and consistently funded reclamation program in Canada. Established in 1973 under the *Land Surface Conservation and Reclamation Act*, the Alberta program aims to restore all disturbed lands (for which no owner can be found) to an ecologically productive state.

The Land Conservation and Reclamation Division of Alberta Environment estimates that, to date, coal mining has disturbed over 6 800 ha in the plains region of the province. Of this, over 1 800 ha have been reclaimed. In the foothills area, where coal mining activities can compete with wildlife habitat, over 3 200 of the 5 144 ha disturbed have been reclaimed (C. Powter, Alberta Environment, Land Conservation and Reclamation Division, personal communication). Reclaiming abandoned strip coal mines for wildlife habitat has been quite successful in Alberta (see Chapter 26).

Alberta's reclamation legislation requires that companies post a security deposit and pay an additional fee per tonne of production as they operate. As the mining company reclaims the disturbed land, the deposit is refunded. Companies are now reclaiming sites as they mine. At the Paintearth coal mine, for example, reclamation is incorporated into the daily mining activities, so that topsoil removed from an area to be mined is frequently placed directly on areas previously mined. Today, activities on Alberta's prime agricultural land must be reclaimed so that productivity equals that existing before disturbance.

The Alberta *Land Surface Conservation and Reclamation Act* was fully applied to the mining of structural materials in 1978. Mining activities prior to this time resulted in abandoned sites covering over 10 000 ha. To date, 163 sites have been reclaimed under Alberta Environment's Land Surface Reclamation Program, mostly for some form of agricultural use (Browning 1987; C. Powter, Alberta Environment, Land Conservation and Reclamation Division, personal communication).

TABLE 11.6

Land area disturbed, utilized, and alienated by mining prior to 1982[a]

Mining type	Area (ha)
Construction aggregates	138 025
Metallic and nonmetallic	103 947
Coal	27 710
Asbestos	4 232
Potash	4 110
Uranium	1 453
Total	**279 477**

[a] Disturbed lands include those affected by open pits, strip mines, underground shaft sites, tailings, waste rock, overburden dumps, slag, and settling ponds.

Source: Marshall (1982).

proposal for two lead–zinc mines near the existing Faro mine is being reviewed by federal and territorial governments under the federal environmental assessment and review process. The company will likely have to post a multimillion-dollar bond, as a condition for project approval, to be used for restoring the site once the mine closes.

The high cost of environmental cleanup and, in particular, the requirements to post bonds have created a great deal of debate within industry and government. Companies have asked governments to consider offering fiscal or tax relief for environmental expenditures.

However, these new approaches, coupled with extensive improvements in modern mining practices, should result in very few instances in which mines operating today leave a legacy of environmental problems when they close.

Land and water use

Canada has not systematically collected accurate data on the nature and extent of land used by the minerals and metals sector. The most recent national assessment available was compiled by Environment Canada (Marshall 1982) and reported in the first state of environment report for Canada (Bird and Rapport 1986). Table 11.6 summarizes this assessment. In total, less than 0.03% of Canada's land area is affected by mining. This represents about 5% of the 5.78 million hectares of land devoted to other built-on land uses, including urban and rural settlements, transportation networks, and farmsteads. Ontario alone accounts for a third of the land area used for mining.

Over 80% of the land used by mining in Canada is taken up by stored discarded materials (e.g., tailings, waste rock, overburden, and settling ponds), open pits, strip mines, and underground shaft entrances. During 1990, the mining industry generated an estimated 950 000 t of tailings and 1 million tonnes of waste rock per day (Intergovernmental Working Group on the Mineral Industry 1991). Although some of this material is used in the construction of roads and dams on the mine site or, in a few coastal operations, discharged directly into the ocean, in most instances it is stored on the mine site. Thus, each year about 650 million tonnes of waste is added to the billions of tonnes of accumulated mining and mineral processing wastes (Intergovernmental Working Group on the Mineral Industry 1991). Depending on the location, size, and life of a mining operation, the land used to store and contain discarded materials varies in size from a few hectares to over 500 ha (Marshall 1982).

The mineral extraction industries recirculate water more often than other industrial water users. The actual water consumption of the mining sector is relatively low compared with other sectors (see Chapter 3). In 1981, mineral extraction accounted for 5% of total water consumption of 3 906 million cubic metres, compared with 62% for agriculture, 16% for municipal services, 13% for manufacturing, and 4% for thermal power plants (Environment Canada 1986*a*).

TABLE 11.7

Examples of the amount of land disturbed and reclaimed between 1982 and 1989

Province	Type of mine	Disturbed land (cumulative hectares)			Reclaimed land, 1989 (ha)	Balance (ha)
		1982[a]	1985	1989		
British Columbia	Coal	6 175	9 800	12 230	4 434	7 796
	Metals	13 000	14 000	17 549	2 898	14 651
Alberta	Coal	8 200	–	11 969	5 018	6 951
Saskatchewan	Coal	6 600	–	9 372	3 947	5 425
	Potash	4 110	–	5 000	–	5 000
Manitoba	Metals	1 986	–	5 000	<100	4 900
New Brunswick	Coal	6 100	–	8 100	2 485	5 615

[a] Based on figures reported in Bird and Rapport (1986).

Source: Marshall (1983); Bird and Rapport (1986); Hart (1989); British Columbia Ministry of Energy, Mines and Petroleum Resources (1990); C. Powter, Alberta Environment, Land Conservation and Reclamation Division, personal communication; J. Bamburak, Manitoba Department of Energy and Mines, personal communication; D. Jillings, Saskatchewan Department of Energy and Mines, Metallic Minerals Branch, personal communication; B. Butler, New Brunswick Department of Natural Resources and Energy, Mines Branch, personal communication.

ACHIEVING A SUSTAINABLE BALANCE

Reclaiming mine sites

By cleaning up mine sites and reclaiming the land for other uses, the minerals and metals sector can become more environmentally sustainable. Reclamation activities have been carried out in all provinces (see Box 11.4). The amount of land disturbed by mining and subsequently reclaimed is not inventoried in many regions of the country, but Table 11.7 gives an indication of the efforts recorded to date.

Coal mines

As of 1989, 42% of the disturbed coal mining areas in Saskatchewan and Alberta had been reclaimed. In British Columbia and New Brunswick, the rate was slightly lower, at 36% and 31%, respectively. In New Brunswick and Nova Scotia, progress has been hampered by acid generation problems. In British Columbia, the steep mountain slopes, unstable waste dumps, dry climate, and thin soils have limited progress.

Metal mines

Metal mines have not been reclaimed as successfully as coal mines because their operations involve high-sulphide waste rock and tailings requiring long-term management and the presence of large open pits. In 1983, an estimated 10% of the area disturbed at these mine sites was reclaimed (Marshall 1983). The only recently available estimate is 17% in British Columbia in 1989 (British Columbia Ministry of Energy, Mines and Petroleum Resources 1990).

Structural materials: pits and quarries

Although mining for sand, gravel, and crushed stone from pits and quarries results in little environmental contamination, the amount of disturbed land is greater than that for all other forms of mining in Canada (Marshall 1982). Because of the costs of transporting structural minerals, these mine sites must be located near their potential markets, and this often means that they create unsightly areas close to population centres.

Canada has no comprehensive national inventory of land disturbance and rehabilitation of pits and quarries. However, the Ontario experience can illustrate reclamation efforts for this type of mining. In 1989, 2 760 pits and quarries were licensed in the province under the *Pits and Quarries Control Act*, primarily in southern Ontario and in the vicinities of Sault Ste. Marie and Sudbury. These licences covered 76 917 ha, of which the Ontario Ministry of Natural Resources (1990) estimated that 19 337 ha required rehabilitation. Of this, 344 ha were rehabilitated in 1989 at a cost of over $10 million. In addition to the land disturbed by licensed operations, there are a large number of pits and quarries in the province that are not yet under the act.

The experience, technology, and planning procedures needed to rehabilitate pits and quarries are readily available and proven (Marshall 1983; McLellan 1983). A major problem in reclaiming older sites is the fact that topsoil and subsoil were rarely stockpiled and often sold. In addition, many older sites were extracted to levels below the water table. Quarries, by their nature, have more limited post-extraction land-use options.

The future

Reclamation of abandoned mines across Canada remains a major issue facing provincial/territorial and federal governments. The number of sites and the high costs involved mean that this issue will continue to require their attention for many years. Today, companies operating in most areas of the country face large financial outlays and strict regulations for site reclamation. However, our ability to successfully rehabilitate some areas, such as those generating acid mine drainage, is still questionable. As these areas pose a long-term risk, Canada still needs to develop specific reclamation techniques to protect the environment from these areas in the future.

Integrating land use

The use of resources can create conflicts between two or more sectors, such as agriculture, forestry, fisheries, recreation, and mining, that compete for the use of the same geographical area. The desire to designate certain areas as parks, claims by native peoples for the ownership of lands, and urban development are additional factors that have a bearing on how the land will be used. The integration of multiple land uses during a project development phase is a key mechanism for addressing environmental concerns and ensuring the sustainability of the land resource over the long term.

In Canada, formal integrated land-use planning is not widespread. Instead, environmental assessment and review processes often serve as the mechanism for raising land-use issues. Windy Craggy, for example, one of the world's largest copper deposits, is located in the Tatshenshini River valley of northwestern British Columbia. If mined, the deposit could yield 1% of the world's copper production for an estimated 20 years, creating hundreds of jobs and contributing considerably to the economic wealth of both British Columbia and Canada. In order to mine this copper, the company would have to strip millions of tonnes of rock from the face of a mountain and move the ore across a glacier for milling.

Recreational and conservation groups are strongly opposed to the project. There are concerns that the waste rock and tailings will generate acid mine drainage, which could affect salmon spawning habitat in the Tatshenshini River. In addition, the valley is close to both Kluane National Park in the Yukon and Glacier Bay National Park in Alaska, and the whole region is considered to be aesthetically unique. The Windy Craggy project is being reviewed under British Columbia's Mine Development and Review Process. In addition, joint federal–provincial environmental assessment public hearings will be held as the review process progresses, because of potential impacts on an international river and on salmon spawning habitat.

Changing technology

Prevention, such as the design of mining, milling, smelting, and refining processes that minimize or eliminate deleterious discharges, is the most effective way to address environmental issues. Since the early 1970s, the industry has been subjected to increasingly stringent environmental assessments and regulations. Through innovative technological advances, the industry has improved its overall industrial efficiency, reduced its energy consumption and the amount of waste it produces, and facilitated the use of recycled metals (see Box 11.5) in producing new products. Researchers are also developing techniques to mitigate existing pollution problems, clean up environmental contamination, and rehabilitate abandoned mines.

These advances have required substantial investments by both industry and governments into research and development, which are expensive and entail a commitment of funds over several years before the results can be applied. Although data are not comprehensive, preliminary estimates indicate that the minerals and metals sector spends about 30% of its research budget on environmental matters. If research to modernize and improve plant efficiency is included, on the premise that improvements to overall efficiency result in better environmental performances, then sector spending may be as high as 50% (M. Wojciechowski, Queen's University, Centre for Resource Studies, personal communication).

With some exceptions, notably the primary nonferrous metals sector, industry research and development expenditures did not grow as much as expected from 1980 to 1989 (Wojciechowski 1990). Some companies have made large investments in environmental research — for example, Noranda Minerals Inc. invested $4.4 million in 1990 and a projected $5 million in 1991 at the Noranda Technology Centre (Noranda Minerals Inc. 1991). However, the trend overall is not known. Environmental research expenditures appear to lag behind those in other countries, if related to gross domestic product, value of production, and sales.

The major environmental issues are too extensive to be resolved quickly or by any one company. This has led increasingly towards the formation of partnerships between operating companies, governments, and research institutions. Research programs aimed at understanding and solving environmental problems include the National Uranium Tailings Program, the Mine Environment Neutral Drainage Program, and British Columbia's Acid Mine Drainage Task Force.

For many years, the Canada Centre for Mineral and Energy Technology (CANMET) of Energy, Mines and Resources Canada has been developing technologies that are of direct or indirect benefit to the environment. CANMET is now in the process of establishing a major group that will concentrate on solving long-term environmental problems. The Centre, in cooperation with industry, has worked to recover coal from tailings ponds, cyanide and trace metals from gold mill effluents, and aluminum from production processes, as well as to develop new metallurgical processes that have the potential to eliminate many of the smelter emissions causing environmental concern.

An alternative approach has been taken in Alberta. Beginning in 1977, the Land Conservation and Reclamation Council has overseen the Reclamation Research Program, a cooperative effort of several provincial departments and industry. The research program has focused on finding answers to the many problems that arise in reclaiming all surface disturbances in Alberta, including the mining of coal and nonmetallic minerals.

Changing attitudes

This chapter has noted a shift in the environmental performance of the minerals and metals sector since the early 1970s. Since the release of the first state of environment report in 1986 (Bird and Rapport 1986), there has also been a shift in attitude and commitment towards improving the industry's image with respect to environmental concerns. This is evident in the greater

BOX 11.5

Recycling metals: the path towards sustainable development

By recycling and reusing metals, the minerals and metals sector can contribute to sustainable development. Recycling metals enables us to conserve nonrenewable resources, provides substantial energy savings and reductions in air and water pollution, and decreases the pressures on existing and future landfill sites.

Recycling of metals is not a new concept. Metals do not lose their mechanical and metallurgical properties, and the economic value of a given metal (e.g., gold or platinum) remains the same whether the metal has been reused or not. Scrap metal represents a valuable resource that can be reused many times.

In Canada, about 50% of the iron (mainly in steel), 55% of the lead, and 40% of the copper produced comes from recycled material. Recycling is big business, generating over $2 billion in 1989, creating jobs, and enabling most smelters to continue operations during uncertain economic times. At the Horne smelter in Rouyn-Noranda, the amount of scrap metal used as feedstock for the smelter increased from 27 000 t in 1977 to 120 000 t in 1989 (Bédard *et al.* 1991). At Inco Ltd., one-third of the annual Canadian production of platinum is recovered from used automobile catalytic converters. Falconbridge, in an agreement with the Government of Ontario, recovers metals from the sludges produced by metal plating companies.

All aluminum scrap collected in Canada for recycling is sent to the United States for reprocessing (e.g., used beverage cans). In North America, about 84 billion beverage cans are produced annually, and almost 70% are recycled (A. Ignatow, Energy, Mines and Resources Canada, Mineral and Metals Commodities Branch, personal communication).

It is perhaps a sad irony that most people view a scrap yard as an unsightly wasteland. The piles of old, rusting cars and other so-called "junk" in fact represent a holding area for metals. The average passenger car, for example, is composed of 58.5% steel, 15.3% iron, 5% aluminum, 0.8% copper, 0.8% lead, 0.6% zinc, and 19% nonmetal materials, such as rubber and plastics (Lemons 1989). The discarded cars and other scrap will eventually be shipped to the nearest steel mill or iron foundry, often subsequently passing through several industries before being returned to manufacturing industries as raw material. The energy saved from reusing scrap metals ranges from 50% in the case of foundry alloys to 74% for iron and steel, and up to 95% for aluminum can production. The benefits include an estimated 86% reduction in air pollution, a 76% reduction in water pollution, and a 97% reduction in mining wastes (A. Ignatow, Energy, Mines and Resources Canada, Mineral and Metals Commodities Branch, personal communication).

Recycling is a growth industry in Canada today. As more and more consumers become aware of the need to recycle the metal products that they discard, the benefits for future and present generations can only increase.

number of partnerships between companies and governments, the industry's improved response to public environmental assessment hearings, its increased experience in dealing with pollution problems, and stricter regulations. The industry is increasingly examining its own environmental record and looking for ways to improve its performance. Individual companies, such as Noranda Minerals Inc., Inco, and Falconbridge, now audit their environmental performance. Mining associations are more active in improving the environmental practices of their member companies, both in Canada and abroad.

In 1989, the Mining Association of Canada produced an environmental policy statement, followed, in 1990, by a guide for environmental practice. Members of the Association, it says, are "committed to the concept of sustainable development which requires balancing good project stewardship in the protection of human health and the natural environment with the need for economic growth" (Mining Association of Canada 1990). As part of this commitment, new mines and processing facilities will endeavour to:

- use energy, air, water, and land prudently;
- minimize discharges to air and water;
- maintain the health of wild organisms;
- recycle and reuse products and reduce wastes;
- dispose of nonrecyclable wastes in an environmentally sound manner; and
- rehabilitate disturbed land.

The policy commitment to sustainable development now provides a broad framework against which the public can assess the industry's progress towards balancing economic development with environmental protection.

CONCLUSIONS

The minerals and metals sector plays a major role in the Canadian economy, providing jobs, contributing significantly to Canada's exports, and making a substantial contribution to the well-being of Canadians. This is likely to continue well into the future. Unfortunately, some of the economic benefits from this sector are offset by costs to the environment.

Canada lacks adequate data regarding the pollution problems associated with the minerals and metals sector. It has insufficient inventories and impact and trend assessments. Without data, it is extremely difficult to determine the progress made to date in developing technological and statutory approaches to pollution control. Despite the lack of consistent information, ongoing treatment and disposal methods at current mining operations appear to be well managed.

Acid mine drainage is one of the industry's most serious environmental problems, at both active and abandoned mines; its role in leaching metals is of particular concern. The physical, chemical, and biological processes controlling the generation of acid in mine wastes are becoming better understood, but finding ways to mitigate the problem still requires a great deal of research, particularly on a site-specific basis. In the meantime, companies must actively treat tailings, waste rock, and effluents to prevent or control acid mine drainage. At abandoned sites, governments in various provinces will continue to face large expenditures to deal with the problem.

The minerals and metals sector has achieved measurable success in addressing some of its most serious environmental problems. The response of the minerals and metals sector to the acid rain issue has met with widespread approval. Although the smelting of nonferrous metals continues to be the greatest source of Canadian emissions responsible for acid rain in many eastern provinces, control measures are now in place through the Canadian Sulphur Dioxide Control Strategy. Industry will most likely meet or exceed the emission targets specified for 1994 using a variety of strategies.

Wastes from past operations, which were not treated and generally not reclaimed, continue to cause environmental problems. In particular, metals deposited from atmospheric emissions and liquid effluents will persist for many years in the bottom sediments in lakes and rivers; they are capable of contaminating other water bodies over time. As well, when containment systems fail at active or abandoned sites, large volumes of tailings and rock containing metals and other harmful compounds can be released to the environment. The delegation of responsibility for cleaning up these spills at abandoned sites, and the costs involved, create additional problems for government agencies at various levels. To prevent these problems from recurring, the stability of both the containment systems and the wastes themselves must be ensured, and the responsibility for managing and financing containment (and in some cases treatment) facilities must be clearly defined.

Other problems, such as saline drainage at potash mines/mills, are not of major importance at this time, but no proven methods of cleanup and site rehabilitation exist. The lack of reclamation techniques and the site specificity of some of the sector's potential environmental problems underscore the need to find the means to decommission these mine sites in an environmentally responsible manner.

The manner in which mines are now designed and the trend towards more stringent air emission and effluent discharge limits, environmental assessments, and reclamation requirements have changed the way mining is carried out in Canada. The extreme examples of long-term environmental degradation caused by mining and smelting over the past several decades probably will not recur in the future. In spite of much progress with respect to current operations, a great deal of work remains to be done in almost every province and territory to clean up and rehabilitate the backlog of abandoned mines on Crown land as well as sites owned by currently operating companies.

The impact of the minerals and metals sector on the environment is changing. Since the early 1970s, the industries have responded to pressure to improve efficiency and address environmental concerns. They have developed a number of innovative techniques to deal with existing pollution problems, and many have strived to exceed regulatory requirements where practical. Recently, there has been a shift towards a more open and proactive approach in addressing the public's environmental concerns. In particular, the mining industry has made an open commitment to the concept of sustainable development. Although there are still many examples of pollution problems at mining, milling, and smelting establishments, the trend towards cooperative problem-solving is an important step in addressing the environmental concerns created by the sector.

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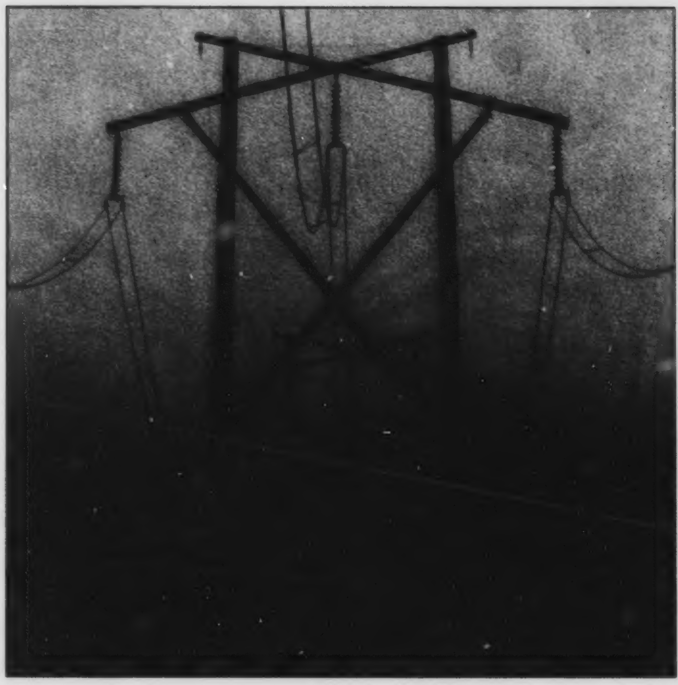

COURTESY OF INDUSTRY, SCIENCE AND TECHNOLOGY CANADA, OTTAWA

HIGHLIGHTS

Canada is one of the most energy-intensive countries in the world, because of its cold climate, large land area, and industrial and urban structures.

■

Building and maintaining the technological infrastructure that supports the production, transportation, and consumption of fuels and electricity account for about 3.7% of all jobs in Canada, 7.1% of the gross domestic product (GDP), and 4.8% of export revenue.

■

Canada obtains 75% of its primary energy from fossil fuels, the combustion of which leads to the three most important global air pollution problems — the warming of the Earth's climate, acidic deposition and urban air pollution associated with ground-level ozone.

■

The human contribution to petroleum pollution of the oceans comes from tanker transport, municipal and industrial wastewater discharges and runoff, atmospheric fallout, and offshore exploration and production. Land spills can also impose environmental costs; contaminating surface water or groundwater, destroying vegetation, killing birds and fish, and causing property damage.

■

Most environmental impacts of electricity use are associated with its generation and transmission. Issues of concern are the large tracts of land that are alienated from other potential uses, the disruption of entire ecosystems by large-scale flooding, and the disposal of radioactive wastes associated with nuclear power generation.

■

The growth in energy demand has been tempered through energy conservation programs, increased efficiency and consumer awareness, and higher prices between 1973 and 1987. In this period, the total amount of secondary energy used per dollar of GDP fell by 30%. Overall, Canada's decline has not been as much as that of most of its major trading partners, and energy demand is showing signs of rising again.

■

The development of Canada's energy resources poses a major dilemma for policy-makers, who must balance the major contribution of energy development to the material welfare of Canadians against its environmental unsustainability if current trends are allowed to continue.

■

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> We face a dilemma: properly used, energy technologies serve as instruments for realizing material well-being across the planet, but continuation of current trends could lead to a degraded environment, yielding a mean and uncertain existence.
>
> — Ged R. Davis (1990)

INTRODUCTION

If humans have become a major influence on the environment, it is largely because of our technological ability to use concentrated forms of energy on a scale that dwarfs the energy available to other species or to our ancestors who lived in preindustrial times. Both of these characteristics of our energy use — its *scale* and its *concentration* or *quality* — are important to understanding how our use of energy has come to have such a pervasive impact on the natural environment.

Ecologists have long recognized that the flow of energy is one of the fundamental characteristics of the organization and state of ecosystems. It is not surprising, therefore, that human activity in the production and consumption of fuels and electricity has come to dominate our lives. Everything that we make and do needs energy, and our ecosystems bear the brunt of the steady accumulation of its waste by-products.

In the language of ecology, humans are "tertiary producers," which means that, even before the development of modern technological energy systems, our energy use was relatively high compared with that of other animals. A well-fed, active Canadian adult maintaining his or her body weight on a 3 000-calorie diet converts 13 MJ of food energy into heat each day (see Box 12.1). In the form of electricity, it is about the same amount of energy required to run an average-sized refrigerator for a day; in the form of the fuel and electricity inputs to a pulp and paper mill, it would make enough

BOX 12.1

Measuring energy: the joule

The joule is the internationally accepted standard unit for measuring all forms of energy.

A litre of gasoline typically contains 35 million joules or 35 megajoules (MJ) of energy; a kilowatt-hour (kWh) of electricity equals 3.6 MJ. Most measurements in this chapter are expressed in multiples of joules, as follows:

Megajoule (MJ): 10^6 joules
Gigajoule (GJ): 10^9 joules
Terajoule (TJ): 10^{12} joules
Petajoules (PJ): 10^{15} joules
Exajoules (EJ): 10^{18} joules

A 30-L gasoline fill-up contains about one gigajoule (GJ) of energy. A petajoule (PJ) is 1 million gigajoules. On average, a city the size of Toronto uses a petajoule of energy for all uses (heat, light, transportation, etc.) about every 15 hours (National Energy Board 1991*a*).

Of course, we could not do all the things we do with fuels and electricity with human power, and this underscores the importance of the second characteristic of modern industrial energy systems — the quality of the energy being used. Although scientists can measure all forms of energy in a common unit, common sense tells us that not all joules are equal. That energy cannot be created or destroyed is perhaps the most well-known scientific fact about energy, but our daily experience tells us that the 35 MJ of energy stored in the chemical bonds of a litre of gasoline or in 10 kWh of electricity can do things that the same amount of energy in the form of low-temperature heat cannot. What differs is the ability of energy to do work, and it is this quality of energy that is degraded when fuels and electricity are used to heat our homes, run our appliances, power our vehicles, power industrial production, and do all the other things we do with energy. Energy forms differ not only in what they can do for us, but also in the technological know-how and in the ecological risks and consequences associated with their use.

newsprint for one or two copies of the daily paper; and in the form of gasoline, it would move a relatively fuel-efficient car 3 km.

In comparison, Canadians use over 825 MJ of energy per day per capita in the form of fuels and electricity, either directly in their cars and homes or indirectly in the form of the goods and services that they produce, consume, and export — more than 60 times the typical well-fed adult's direct use of food energy. It adds up to a prodigious quantity of fuel and electricity. Thus, the extraction, processing, transporting, and final use of energy resources in this country constitute a major category of human activity that has widespread influence on the state of the environment.

On an average day in 1989, Canadians extracted from the earth some 190 000 t of coal, 270 million litres of crude oil, 300 billion litres of natural gas, and 17 000 t of uranium ore. In addition, most of the major river systems in the country have been dammed and restructured to facilitate hydroelectric production, which provides nearly two-thirds of all the electricity consumed in Canada. These primary energy resources are then processed into fuels and electricity and moved by road, rail, pipeline, and transmission line on a transportation network that reaches virtually every home, factory, business, and motor vehicle in the country. Building and maintaining the technological infrastructure that supports the production, transportation, and consumption of fuels and electricity are a major sector of the Canadian economy, accounting for about 3.7% of all jobs, 7.1% of the gross domestic product (GDP), and 4.8% of export revenue (Government of Canada 1991).

In Canada's first state of the environment report (Bird and Rapport 1986), references to the influence of fuels and electricity production and consumption can be found in the discussion of the state of every ecozone in the country. Since then, we have had numerous reminders of the connections between energy and environment.

In 1987, the World Commission on Environment and Development (1987) released its final report at the United Nations General Assembly, devoting an entire chapter to energy and concluding that while "a sustainable energy pathway is crucial to sustainable development, we have not yet found it." In Canada, environment has continued to move up on the energy policy agenda — an agenda traditionally dominated by the economic development objectives and security of oil supply.

Canadians have concluded that "environmental goals should be accorded the same importance as other economic and social goals in the planning, development and use of energy" (Energy Options Advisory Committee 1988). Further, the "environment is likely to be the single most important issue confronting the energy sector in Canada and around the world over the next several years. The reason is clear: the environmental effects of energy production and consumption are pervasive, playing an important if not dominant role in many of the key environmental issues of the day" (Energy, Mines and Resources Canada 1990*a*).

This chapter examines some of the impacts that the use of energy has on Canada's environment, recent trends in those impacts, and the challenges being faced in striving to achieve an energy future that is compatible with sustainable development. It is a vast topic, and the treatment is therefore selective and focuses on the more persistent environmental stresses caused by energy production, transportation, and use.

TABLE 12.1

Canada's energy resource base

Type	Resource base
Crude oil	•remaining established conventional reserves in western Canada of 704 million cubic metres, with further ultimate potential estimated at over 1 billion cubic metres. •discovered conventional resources in the frontier areas assessed at 619 million cubic metres, with ultimate potential projected at 4 billion cubic metres. •Canada's oil sands represent the world's largest known oil deposits, with an estimated 270 billion cubic metres of original bitumen in place. Currently, some 10 billion cubic metres of bitumen are estimated to be recoverable. •Canada's 1989 production of crude oil was 90 million cubic metres.
Natural gas	•remaining established reserves of marketable natural gas of 2 trillion cubic metres in western Canada and 1 trillion cubic metres in frontier areas. •ultimate resource potential in western Canada ranges from 1.4 trillion cubic metres to 2.5 trillion cubic metres, with up to 7 trillion cubic metres in frontier areas. •marketable production was 96 billion cubic metres in 1989.
Coal	•recoverable coal reserves of 7 billion tonnes, "measured" resource potential of 21 billion tonnes, and "indicated/inferred" resource potential of 58 billion tonnes. Production for 1990 was about 68 million tonnes.
Hydroelectric	•total gross existing and potential hydroelectric capacity of 205 000 MW, with 60 000 MW currently in operation or under construction, 94 000 MW identified as technically feasible, and the remainder considered planning potential.
Uranium	•uranium resources of current economic interest estimated at 580 000 t. Production in 1990 was 8 750 t.
Biomass and peat	•Canada's biomass resource base could provide as much as 133 million tonnes of fuel per year on a sustained basis (forest — 110, agriculture — 7, municipal wastes — 16). Peat resources total approximately 335 billion tonnes.

Source: Energy Options Advisory Committee (1988); Statistics Canada (1990); Energy, Mines and Resources Canada (1991*a*).

ENERGY SUPPLY AND USE

Canada is richly endowed with a wide range of energy resources (see Table 12.1). Production and levels of growth in the past decade are provided in Table 12.2. In addition to these developed energy sources, Canada has potential alternative energy opportunities from wind, the sun, and other sources.

In 1989, primary energy production from all sources was 12 018 PJ (Fig. 12.1). In the same year, primary energy demand was 79% of primary production. *Primary energy demand* represents the total requirement for all uses of energy, including energy used by the final consumer (*end-use demand*), intermediate uses of energy in transforming one energy form to another (e.g., coal to electricity), and energy used by suppliers in providing energy to the market (e.g., pipeline fuel). Production is larger than domestic demand because Canada is a net exporter of natural gas, oil and petroleum products, coal, and electricity. Canada was also the world's largest exporter of uranium in 1990.

Canada's energy resources are distributed unevenly across the country. Thus, the large distances separating the sources of supply from the main centres of demand (Figs. 12.2 and 12.3) have had significant implications for the way in which energy is used in Canada and, therefore, its environmental impact:

1. These distances have required the development of an extensive transportation network comprising hundreds of thousands of kilometres of oil and gas pipelines, electricity transmission lines, and railway lines for coal movement. The transportation of energy over large distances consumes energy and occupies large amounts of land in rights-of-way.

2. The geographical distribution of Canada's energy resources has also led to significant differences in regional energy consumption patterns: with many large rivers, Quebec relies on hydroelectric power for almost all of its electri-

TABLE 12.2

Energy production, supply, demand, and prices, 1980–89

	1980	1985	1989	% change, 1980–89
I. Production, supply, and demand				
Coal supply and demand (millions of tonnes)				
Production	38.7	60.9	70.5	+ 82
Imports	15.8	14.6	14.5	− 8
Total supply	52.5	75.5	85.0	+ 62
Exports	15.3	27.4	32.7	+114
Domestic demand	37.3	48.7	53.9	+ 44
Uranium supply and demand (thousands of tonnes)				
Production	7.2	10.9	11.4	+ 58
Exports	NA	7.9	9.4	NA
Domestic demand	1.0	1.3	1.8	+ 80
Natural gas supply and demand (billions of cubic metres)				
Indigenous supply	78.1	87.0	108.0	+ 38
Production (marketable)	70.1	77.4	98.4	+ 36
Exports	22.6	26.2	37.9	+ 68
Domestic demand	49.9	52.4	60.0	+ 25
Petroleum supply and demand (millions of cubic metres)				
Production	102.7	105.0	114.3	+ 11
Imports	34.7	21.3	39.1	+ 13
Total supply	137.4	126.3	153.4	+ 12
Exports	28.1	44.2	57.0	+103
Domestic demand	109.0	88.1	99.5	− 9
Electricity supply and demand (terrawatt-hours)				
Production				
Hydro	251.0	300.7	288.5	+ 15
Conventional thermal	79.8	88.6	119.8	+ 50
Nuclear	35.9	57.1	75.4	+110
Total production	366.7	446.4	483.7	+ 32
Imports	2.9	2.7	13.0	+348
Total supply	369.6	449.1	496.7	+ 34
Exports	30.2	43.0	22.3	− 26
Domestic demand	339.4	406.1	474.4	+ 40
II. Selected prices				
Gasoline and oil (cents per litre)				
Gasoline				
Unleaded	27.9	53.5	51.6	+ 85
Leaded	25.9	51.2	51.3	+ 98
Heavy fuel oil	10.8	20.9	11.3	+ 5
Automotive diesel	NA	47.5	47.4	NA
Residential heating oil	17.1	38.3	30.2	+ 77
Natural gas [end-user prices] (dollars per gigajoule)				
Residential sales	2.79	4.92	4.59	+ 65
Commercial sales	2.32	4.16	3.91	+ 68
Industrial sales	1.91	3.30	2.41	+ 26
Average	2.20	3.90	3.32	+ 51
Electricity [end-user prices] (cents per kilowatt-hour monthly consumption)				
Residential	3.32	5.04	5.89	+ 77
Commercial	2.78	4.29	4.97	+ 79
Industrial	2.29	3.49	4.03	+ 76

NA = not applicable

Source: Energy, Mines and Resources Canada (1990*b*).

city generation; Alberta and Saskatchewan, on the other hand, use primarily local coal reserves. Natural gas is used extensively for home heating in all provinces west of Quebec but not at all in the Atlantic provinces; as a result of a smaller range of available alternatives, oil accounts for a far greater share of energy consumption in the Atlantic provinces than in the rest of the country (Table 12.3).

3. The large distances separating domestic sources of supply and demand have also made it economically advantageous for Canada to trade extensively in energy rather than meet all its needs from indigenous sources. Thus, Canada exports oil and gas from the western provinces, imports oil into eastern Canada and coal into Ontario, and engages in extensive cross-border electricity exchanges with the United States. The fact that Canada holds abundant reserves of energy relative to domestic needs and shares a continent with the world's largest industrial economy has, of course, also encouraged it to export.

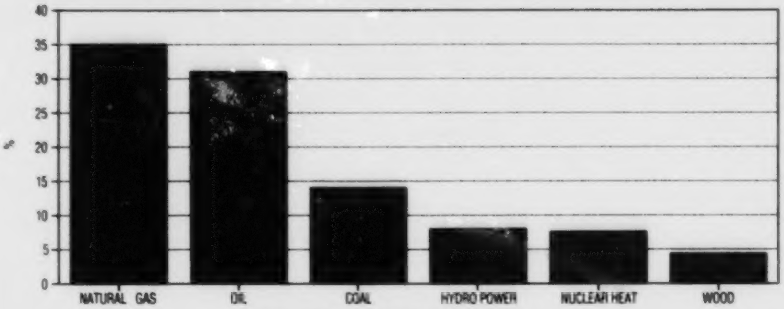
As a result of these factors, the environmental consequences of energy use differ markedly across the country.

Both the sources and the amount of energy used in Canada have changed dramatically since World War II. The evolution of Canada's primary energy use (Fig. 12.4) reflects much about the evolution of Canada itself: the economic stagnation of the 1930s, the rapid economic growth of the postwar period, and the impacts of higher energy prices and increased efficiency in the 1970s and 1980s. Since the early 1930s, Canada's primary energy demand has grown nearly sevenfold. Although less spectacular, the growth in per capita energy use has also been substantial. Per capita Canadian domestic primary energy consumption for all uses was 2.3 times more on average in 1990 than in 1930.

Figure 12.5 illustrates the per capita growth in primary energy use in Canada between 1960 and 1990. Energy use does not, in itself, measure environmental stress, but it is used here as a proxy for the level of impact that it can have

FIGURE 12.1

Primary energy production in Canada in 1989, by resource

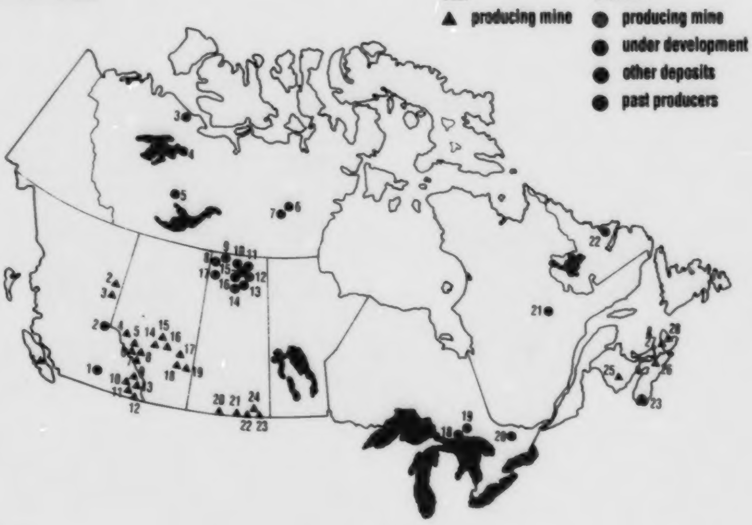


TOTAL: 12 018 PJ (EXCLUSIVE OF URANIUM EXPORTS)

Source: National Energy Board (1991*b*).

FIGURE 12.2

Uranium and coal mines in Canada



Coal
Active mine

1. Quiness
2. Bullmoose
3. Quintette
4. Smoky River
5. Obed
6. Gregg River
7. Luscar
8. Coal Valley
9. Fording River
10. Greenhills
11. Balmer
12. Coal Mountain
13. Line Creek
14. Highvale
15. Whitewood
16. Genesse
17. Vesta
18. Paintearth
19. Montgomery
20. Poplar River
21. Utility
22. Dam
23. Bienfait
24. Costello
25. Minto
26. Westville
27. St. Rose
28. Sydney; Point Aconi

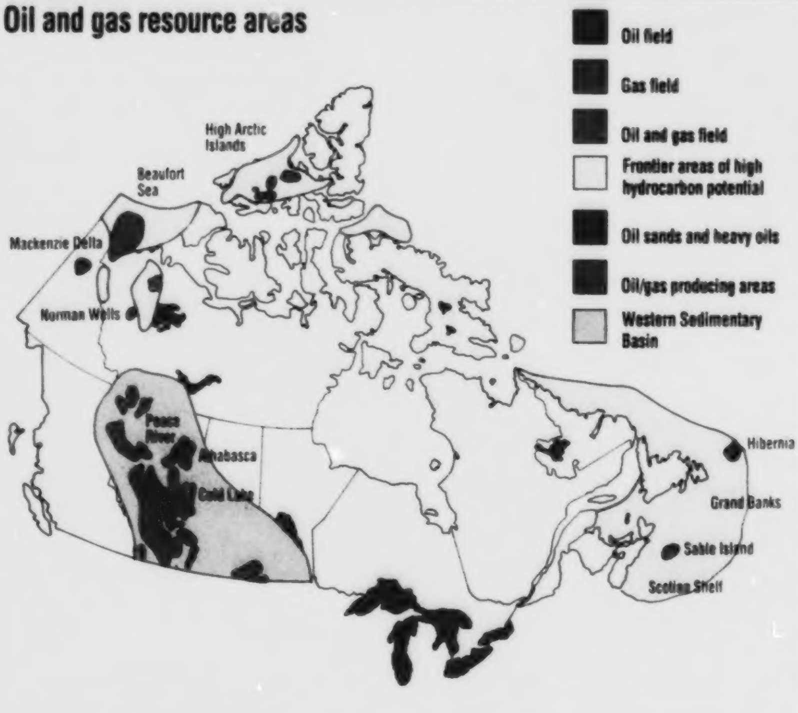
Uranium
Mine

1. Blizzard
2. Rexspar
3. Dismal Lakes
4. Port Radium
5. Marian River
6. Kiggavik
7. LGT
8. Maurice Bay
9. Beaverlodge
10. Fond-du-Lac
11. Wolly
12. Rabbit Lake (incl. Eagle Pt.)
13. Cigar Lake
14. Key Lake
15. Midwest Lake
16. McArthur River
17. Cluff Lake
18. Elliot Lake
19. Agnew Lake
20. Bancroft
21. Otish Mountains
22. Makkovik
23. Millet Brook

Source: Energy, Mines and Resources Canada (1991*b*); National Energy Board (1991*b*).

FIGURE 12.3

Oil and gas resource areas



Source: Energy, Mines and Resources Canada 1984*a*, 1984*b*, 1985; Environment Canada 1988*a*; National Energy Board (1991*b*).

on the environment. Generally, there is a strong correlation between energy use and environmental stress. The figure shows that per capita use of primary energy (total energy available from natural resources) in Canada has returned to its long-term upward trend after a brief fall in the 1980s. The decline in the 1980s had a number of causes, including high oil prices, economic recession, and a large-scale conservation effort.

Canada's energy endowment has directly and indirectly influenced the development of Canada's economy. Its direct contribution to the economy in terms of the GDP, exports, and employment has already been noted in the introduction. In addition, non-residential energy investment has accounted for 17.4% of total business investment between 1983 and 1987 (Government of Canada 1991). At one time or another, almost all provincial governments and the federal government have relied on the development of energy resources to create jobs or spur investment. Its indirect influence has been equally great, but more subtle. It has allowed the emergence of one of the most energy-intensive lifestyles in the western world. This lifestyle has been assisted by the trend of Canadian governments to promote the availability of cheap energy as a tool of industrial and economic policy. In the 1970s, for example, the federal government kept Canadian oil prices below world levels to cushion the inflationary impact of the "energy crisis" and to increase the competitive advantage of exporting companies. During the same period, Alberta encouraged the growth of a provincial industry based on its abundant gas reserves. Today, Quebec relies on plentiful and cheap electricity to attract investors in the aluminum industry.

It is also important to note the distinction between energy intensity and energy efficiency in discussing the role of energy consumption. *Energy intensity* measures energy use per capita or per unit of economic output (gross national product). Such measures are often used to compare energy use internationally. *Energy efficiency* measures the ratio between the energy content of a fuel and its useful output when burned. Energy is used inefficiently when the same service (e.g., heat, light, motion) could be provided for a lower input. The fact that a country uses a lot of energy per capita (high energy intensity), however, does not necessarily imply that it uses this energy inefficiently.

Although Canada is one of the most energy-intensive countries in the world, there are a number of significant reasons for this. They include:

- a climate 40% colder on average than the United States, France, Germany, or Italy;
- a large land area, leading to a high demand for transportation services;
- an industrial structure based on the energy-intensive production of primary commodities (e.g., pulp and paper, minerals, agricultural goods); and
- an urban structure whose characteristics of low density and a preponderance of individual dwelling units create large demands for transportation and space heating.

Although it has contributed to Canada's economic growth, the development of Canadian energy resources has imposed significant environmental costs. In a modern industrial society like Canada, this fact poses a major dilemma for policy-makers: on the one hand, energy development, for both domestic and export use, makes a major contribution to the material welfare of Canadians; on the other hand, the continuation of current trends is environmentally unsustainable and thus threatens the very lifestyle our energy use has made possible in the first place.

The domestic demand for primary energy in Canada was 9 585 PJ in 1989 (Fig. 12.6). The consumer, however,

TABLE 12.3

End-use fuel shares (%) by region, 1989

End use	B.C. and territories	Prairies	Ontario	Quebec	Atlantic
Electricity	18	12	18	34	21
Natural gas	23	48	31	13	0
Oil (nontransportation)	11	11	12	17	29
Oil (transportation)	26	23	25	26	34
Renewables[a] and steam	20	2	4	7	13
Others[b]	2	4	10	3	3
Total	**100**	**100**	**100**	**100**	**100**

[a] Includes wood, wood waste, solar, wind, and municipal solid waste.

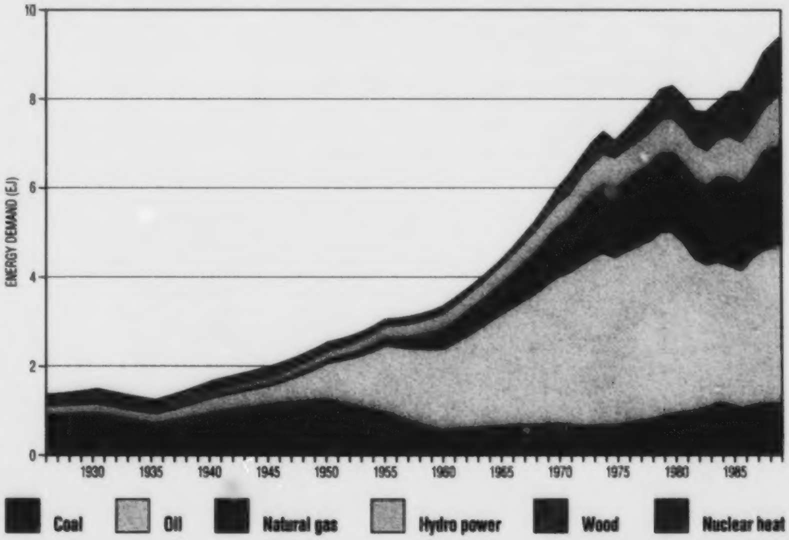
[b] Includes coal, coke, coke oven gas, and natural gas liquids.

Note: Percentages have been rounded off.

Source: National Energy Board (1991*b*).

FIGURE 12.4

Domestic demand for primary energy in Canada, 1926–89



Note: Data are cumulative.

Source: Statistics Canada (1978,1991).

does not use all of this energy directly: 14% (1 357 PJ) is lost in the form of waste heat at thermal power plants when nuclear power or fossil fuels are burned to produce electricity. The production of electricity by steam-driven generators (whether the steam is raised by fuel combustion or by nuclear fission) is a fundamentally inefficient process, averaging about one unit of electricity output for every three units of combustion or nuclear heat inputs.

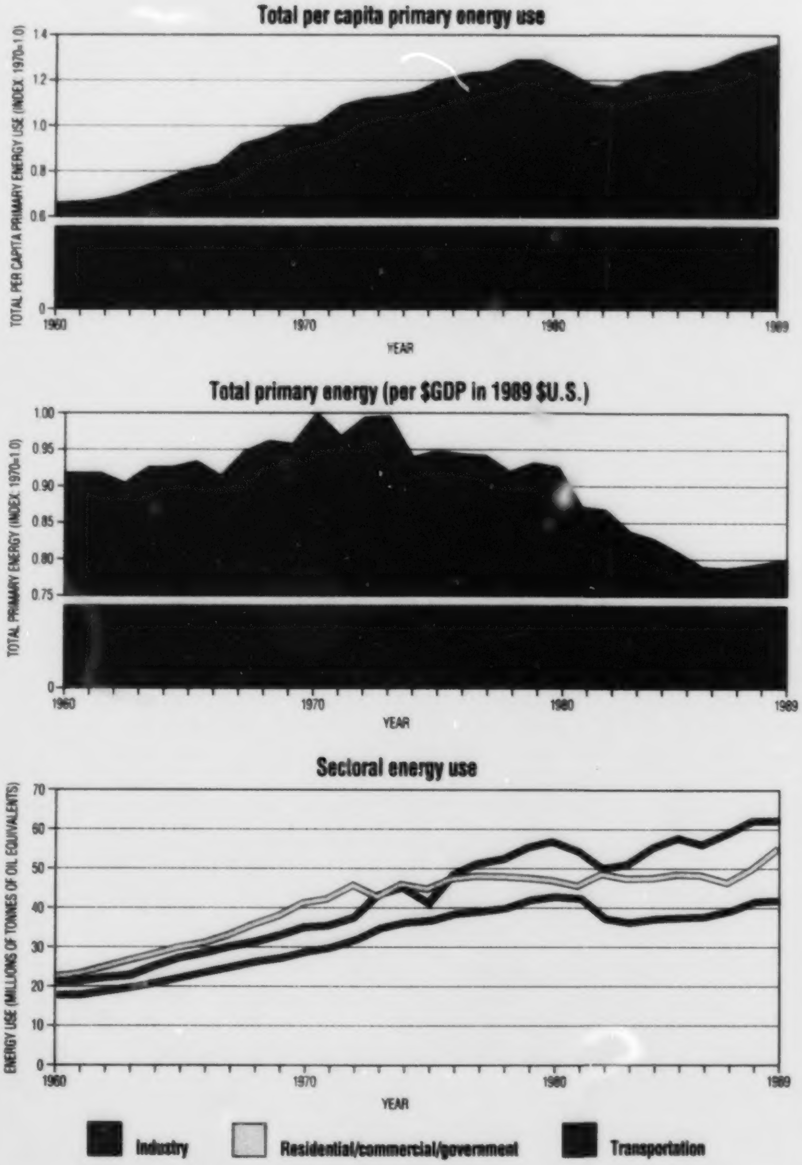
The demand for *secondary energy* in 1989 was therefore only 86% of the primary energy demand. The final consumer or end-use demand was 6 959 PJ, or 73% of the demand for primary energy (Fig. 12.7). The difference between secondary energy demand and final consumer or end-use demand is accounted for by nonenergy uses (petrochemical feedstocks, asphalt, lubricants, greases) and the energy industry's own use and losses — e.g., pipeline fuel and reprocessing fuel for natural gas, energy industry fuel for natural gas liquids, losses in the production of coke for coal, transmission and distribution losses of electricity, and refinery and terminal consumption for oil (National Energy Board 1991*b*).

Fully 77% of the end use of energy demand is in the form of fuels, with virtually all of the remainder being provided by electricity. The extent to which fuel combustion dominates energy end use varies by sector. Commercial and institutional buildings constitute the smallest of the major end-use sectors but are the least fuel-dependent, with 43% of energy end use in this sector being provided by electricity. The direct use of coal (as opposed to its use to make electricity) is confined to a small number of large industrial applications — mostly for steelmaking but also in cement plants and some industrial boiler applications. The use of refined petroleum products has been reduced dramatically in recent years in all sectors except transportation, where it still accounts for virtually 100% of energy end use.

The relative share of total final demand represented by the residential, transportation, commercial, and industrial sectors has been quite stable over time. Nationally, about 28% of total energy consumed is for transportation (Fig. 12.7); over half goes to automobiles, and two-thirds of that is in urban areas. In a typical urban area, 90% of the transportation energy is used to move people, whereas the remaining 10% is for movement of goods, principally by truck. Journey-to-work dominates the trips made, followed by social, recreational, and shopping trips. Energy use in government and commercial buildings (shopping malls, office buildings, schools, warehouses, hospitals, etc.) accounts for an additional 13%. Finally, industrial energy requirements account for 38% of energy end use. Three very energy-intensive industries — pulp and paper, chemicals, and primary metals — account for half of all industrial use. Residential energy use varies widely, depending on household size, climate, the air tightness and insulation levels of the house or apartment

FIGURE 12.5

Measures of energy use in Canada, 1960–89


Total per capita primary energy use

Total primary energy (per $GDP in 1989 $U.S.)

Sectoral energy use

Source: Indicators Task Force (1991).

building, the efficiency of the heating system, the temperature and amount of hot water used, the number and type of appliances, and other factors.

In 1989, the average Canadian household used 96 GJ to heat its home, 21 GJ to heat water, and 24 GJ to run appliances. Adding the average 90 GJ used as automobile fuel (almost all gasoline, with some contributions from diesel fuel, propane, and natural gas), the average household final demand for fuels and electricity in Canada in 1989 totalled 231 GJ, an amount of energy equivalent to 6 600 L of gasoline (Marbek Resource Consultants 1989).

A schematic picture of the overall flow of energy resources in the Canadian economy is illustrated in Figure 12.8, "use of resources in the production and consumption of energy". Even in this simplified form, the diagram reveals the degree to which energy provides the foundation of our industrial society, and how so many potential stresses on the environment can arise from the activities associated with its production, conversion, transport, and consumption.

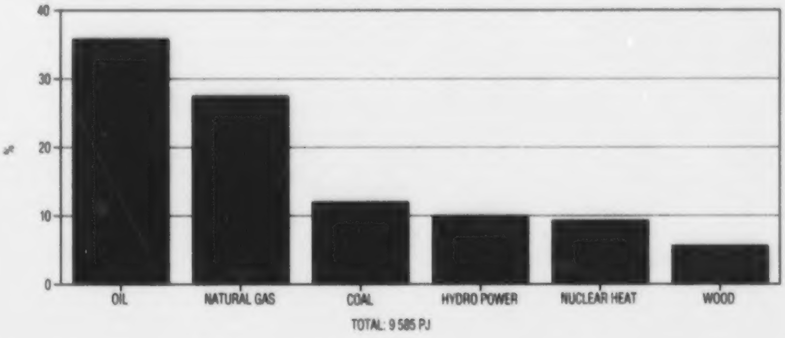
ENVIRONMENTAL IMPACTS OF ENERGY

The magnitude and complexity of environmental impacts associated with different energy technologies can be appreciated only by examining the entire chain of events that leads to the point of final end use, such as running an automobile (Table 12.4). The environmental impacts associated with driving an automobile are not limited to the emissions of nitrogen oxides (NO_x), carbon monoxide (CO), and hydrocarbons from the exhaust pipe. For example, the gasoline powering the car would have been bought at a service station where gasoline may leak from aging underground storage tanks. The service station selling the gas would likely have received its supplies by truck from a refinery, which may have environmental impacts as it transforms crude oil into refined products such as gasoline. Refineries are typically supplied by ships or pipelines. Both of these methods of transport entail environmental risks arising from accidental spills of crude oil at sea or on land. Finally, the development of oil reserves imposes environmental costs, which vary with the nature and location of the deposit to be produced and the technology applied.

In addition, the use of the automobile requires an extensive infrastructure, primarily in the form of roads, bridges, and borrow pits for the extraction of construction materials. As well, the automobile must ultimately be disposed of as waste materials or recycled metals. Each event in the chain has its own environmental impacts.

FIGURE 12.6

Domestic primary energy demand in Canada in 1989, by source

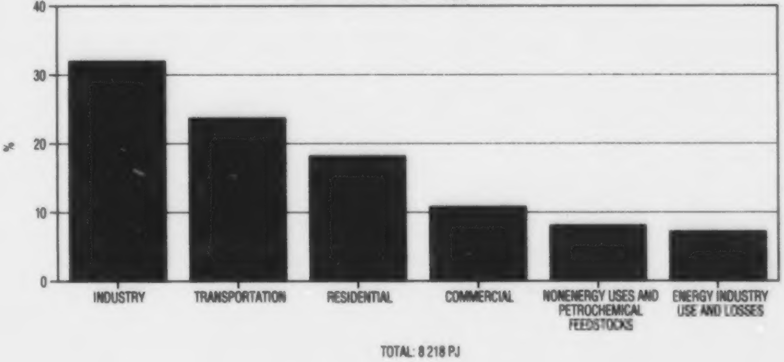


Source: National Energy Board (1991*b*).

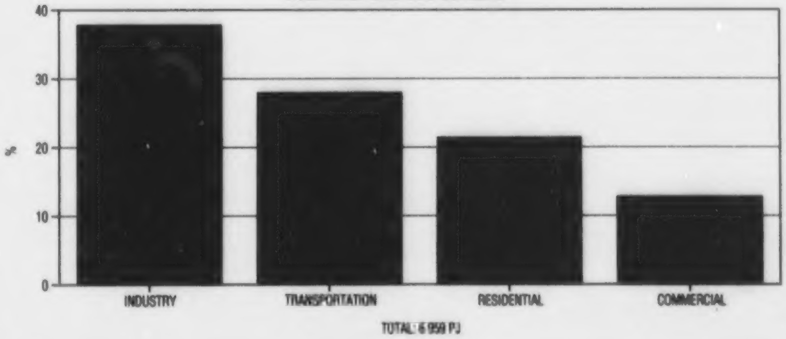
FIGURE 12.7

Total secondary energy use and final end-use demand in Canada in 1989, by sector

Total secondary energy use



Total final end-use demand



Source: National Energy Board (1991*b*).

The automobile illustrates the difficulty of reducing the environmental impacts of energy use. The car has had a huge influence on the design of North American cities, spurring extensive low-density suburban growth, particularly after World War II. This pattern of development, in which distances between home, job, and services are often large, creates a built-in demand for cars by making competing sources of transportation uneconomic or inconvenient. Private car commuting thus tends to be inversely related to land-use intensity, as measured by the number of people and jobs per square kilometre. The fact that car ownership has become an integral element of our lifestyle makes it particularly difficult to implement policies to reduce the environmental impact of the automobile. Statistics Canada (1991) indicates that in 1986 over 84% of Canadian households reported expenditures on the operation of private motor vehicles, and that the passenger car now accounts for 80% of all intercity travel.

A life-cycle analysis of electricity or other fuels would lead to similar observations. Virtually all aspects of the energy sector have effects that are potentially damaging to the environment. In practice, available technology and preventative methods enable many of these effects to be reduced so that the net impacts are broadly acceptable to society in most cases. Yet, as revealed by the spirited public debates of the last two decades over the use of nuclear energy, the construction of northern pipelines, large hydroelectric dams and reservoirs, and global warming, the nature and extent of the environmental risks posed by various energy technologies remain highly controversial.

This section focuses on changes in environmental quality related to energy production, transportation, and use.

Fossil fuels

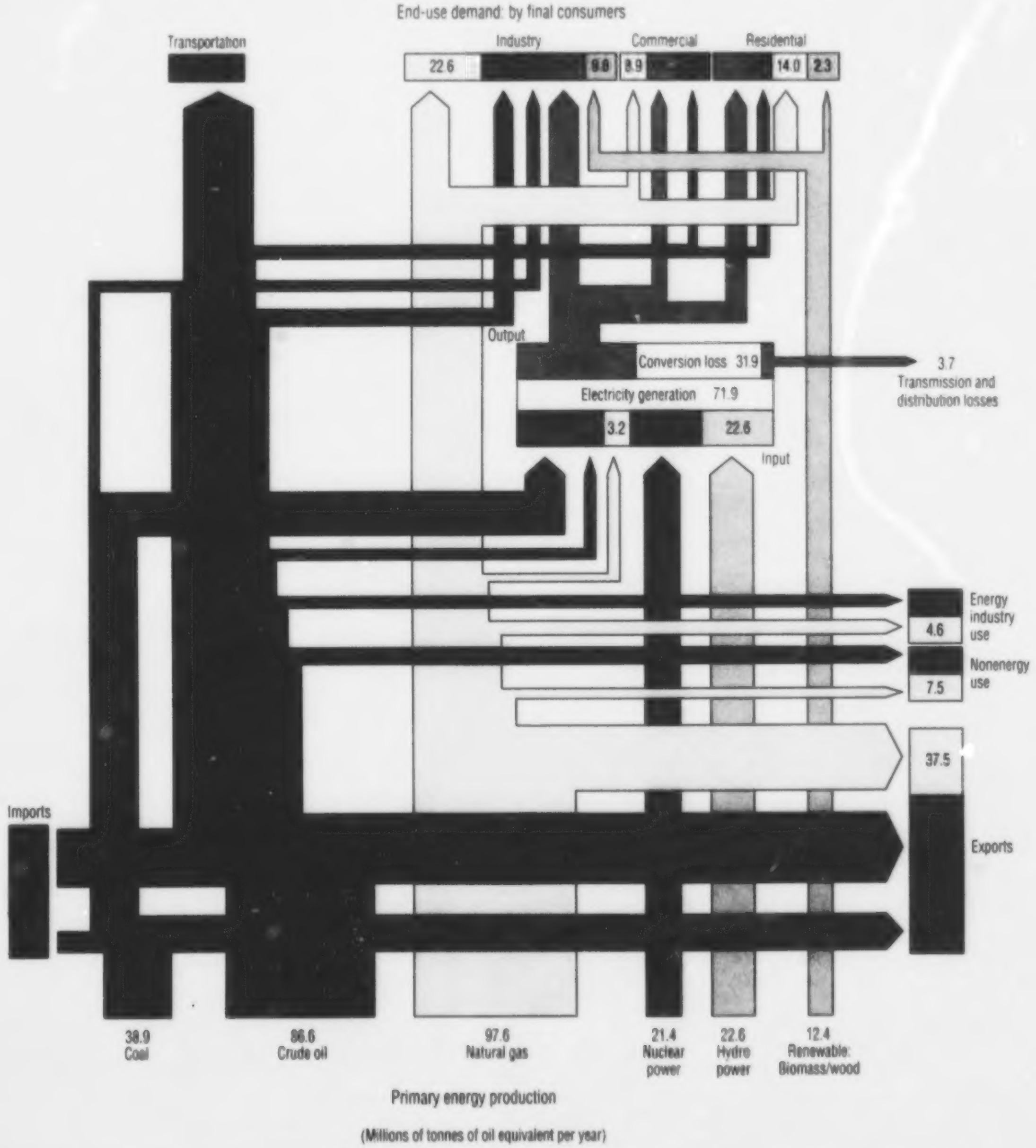
Canada obtains three-quarters of its primary energy from oil, natural gas, and coal, collectively called fossil fuels

FIGURE 12.8

Canadian energy flows, 1989

The energy flow diagram for 1989 illustrates that fossil fuels are highly versatile. Crude oil (red) is first processed in refineries, where it is converted to gasoline, diesel, and aviation fuel for its largest single use, transportation. Both oil and natural gas (yellow) are widely used by industry, residential, and commercial consumers as an energy source, and as a feedstock for nonenergy uses, in the production of chemicals, plastics, fertilizers, etc. Only a small percentage is used to generate electricity.

Most of the coal consumed in Canada is used to generate electricity. However, in Canada, a very high percentage of domestic oil, gas, and coal production is exported. Hydro power and nuclear power make up 16% of the primary energy supply. Wood use by industry and residential consumers accounts for 4% of the total primary energy supply.


End-use demand: by final consumers
Transportation
Industry
Commercial
Residential
22.6
9.8
8.9
14.0
2.3
Output
Conversion loss 31.9
3.7
Transmission and distribution losses
Electricity generation 71.9
3.2
22.6
Input
Energy industry use
4.6
Nonenergy use
7.5
37.5
Exports
Imports
38.9
Coal
86.6
Crude oil
97.6
Natural gas
21.4
Nuclear power
22.6
Hydro power
12.4
Renewable: Biomass/wood
Primary energy production
(Millions of tonnes of oil equivalent per year)

Note: Schematic diagram adapted from Davis (1990). Data presented have been rounded off and exclude small amounts of energy sources when they totalled less than 1% of the total energy input (e.g., biomass/wood for electricity) or output (e.g., residential use of coal).

Source: National Energy Board (1991*b*).

TABLE 12.4

Energy and the automobile

Activity and infrastructure	Year	
Extraction and refining[a,b]	**1989**	**1980**
•total no. of producing oil wells	38 000	23 000
•oil wells drilled annually	2 000 (1990)	1 450 (1986)
•oil refineries	29 (1990)	37
Distribution[c]	**1989**	**1984**
•oil pipelines (km)	34 862	31 894
•pumping stations	257	223
Delivery[d]	**1987**	–
•retail gas station outlets	18 878	–
•estimated underground storage tanks at outlet	75 512	–
Use[e]	**1988**	**1980**
•estimated no. of passenger cars operated	8 157 000	7 128 000
Service rendered[e]	**1988**	**1980**
•distance travelled (km, 000s)	141 000	116 350
•distance travelled per vehicle (km)	17 383	16 322
•consumption per vehicle (L)	2 087	2 688
•fuel consumption ratio (L/100 km)	12.0	16.5
Infrastructure[f]	**1988/89**	**1985**
•federal highways (km)	14 735	13 837
•provincial/territorial highways (km)	277 268	267 979
•municipal highways (km)	598 528	579 652
•highways total (km)	879 530	861 468
•fuel consumed (total litres, millions)	17 020 (1988)	19 160 (1980)

[a] Canadian Petroleum Association (1991).

[b] National Energy Board (1991*a*).

[c] Statistics Canada (1985, 1989).

[d] Environment Canada (1988*b*).

[e] Statistics Canada (1991).

[f] Roads and Transportation Association of Canada (1990).

because of their geological origin: they have formed during the deposition and chemical transformation of organic matter in sedimentary rock over millions of years. Fossil fuels are of particular concern because of their large contribution to "greenhouse gas" emissions and therefore global climatic change.

The use of fossil fuels leads to three major kinds of environmental impacts:

1. At the point of *production*, environmental issues associated with fossil fuels concern primarily land uses. These include physical disturbance to the land (e.g., a mine site), conflict with other land uses (e.g., oil exploration in an important wildlife habitat), and risks to local environmental values (e.g., oil spills).

2. The *transportation* of crude oil raises additional environmental risks that the other major fossil fuels — coal and natural gas — do not. Because it is the most widely traded commodity in the world, oil has often been spilled during its transportation, sometimes with disastrous results.

3. At the point of *consumption*, the environmental issues are primarily atmospheric. The burning of fossil fuels releases a variety of emissions, including carbon dioxide (CO_2) (a major contributor to climatic warming), sulphur dioxide (SO_2) and nitrogen compounds (the most important precursors of acid precipitation), CO, volatile organic compounds (VOCs), and particulates (all of which affect urban air quality). Although these pollutants are initially discharged into the air, they often end up in aquatic ecosystems where they can cause significant damage. Progress has been made in reducing all these emissions, except for CO_2, for which no viable abatement technology currently exists.

The fossil fuel share of primary energy in Canada dropped dramatically between 1970 and 1985 (Fig. 12.9). The relative decrease in fossil fuel consumption is attributed to a number of factors, including increases in domestic oil prices and the strong growth of hydro and nuclear energy. The increase in the fossil fuel share of primary energy demand in the last two years has been concurrent with lower oil prices.

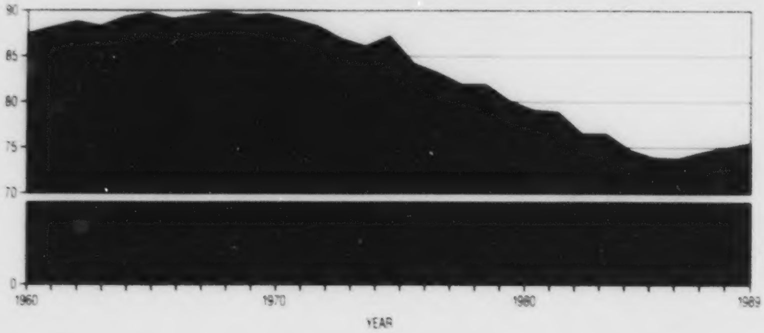
Over 70% of our energy is still dependent on fossil fuels, and, because of their accessibility, versatility, and conversion capability as well as our dependence on them as a transportation and heating fuel, they will continue to be essential for decades to come. Therefore, technologies to ameliorate their environmental effects will have to be pursued.

Atmospheric emissions

The mobility and relatively low mass of the atmosphere make it highly susceptible to large-scale transformations. The three most important global air pollution problems — the warming of the Earth's climate, the acidification of the environment, and urban air pollution associated with ground-level ozone — are attributable in large measure to the combustion of fossil fuels. The principal emissions produced from the production, transportation, and burning of fossil fuels are CO_2, SO_2, CO, nitrogen compounds (NO_x, N_2O), methane, VOCs, and particulates (e.g., carbon soot). Figure 12.10 indicates the sectoral sources for these emissions.

FIGURE 12.9

Fossil fuel intensity of primary energy demand, 1960–89



Source: Indicators Task Force (1991).

Recent emissions estimates comparing the relative contribution of gaseous emissions from the energy sector with those from the nonenergy sector confirm the dominant role the energy sector plays as a source of human-made emissions of environmental concern (Fig. 12.11). The energy sector accounts for the major portion of human-made emissions of CO$_2$, NO$_x$, and VOCs, accounting for approximately 92%, 95%, and 60%, respectively. The energy sector accounts for about 45% of the SO$_2$ emissions and 16% of total methane emissions.

Climatic change

Energy use directly contributes to three greenhouse gases: CO$_2$, nitrous oxide (N$_2$O), and methane. CO$_2$ is by far the most important greenhouse gas emitted in Canada. Globally, CO$_2$ represents about 55% of all anthropogenic emissions that contribute to climate warming (see Fig. 2.12 and Chapter 22). From a sectoral point of view, transportation, power plants, and stationary combustion sources (industrial boilers, residential and commercial heating) account for most of the Canadian greenhouse gas emissions.

In Canada, emissions of CO$_2$ have been increasing steadily. Between 1920 and 1989, Canadian CO$_2$ emissions from energy increased by about 500% (Fig. 12.12). The rate of increase accelerated in the period after 1945, coincident with increases in economic growth and fossil fuel use. Globally, anthropogenic CO$_2$ emissions have more than tripled since 1950 (Indicators Task Force 1991). Canada's share is only 2% of the total global emissions (see Chapter 22).

Canada is a relatively low producer of CO$_2$ per unit of energy demand. CO$_2$ emissions in relation to primary energy (in tonnes of oil equivalent) are shown in Figure 12.13. The long-term trend in CO$_2$ emissions in relation to economic growth has been downwards, as efficiency of energy use has increased and fuel switching to natural gas, hydro, and nuclear power has taken place. However, this downward trend has a limit, unless there is a continuing increase in the share of hydro and nuclear energy. Although there is some room for improvement in CO$_2$/energy intensity in Canada, it is modest. Indeed, the intensity of CO$_2$ emissions has begun to rise again in the past five years, after declining 24% in the period 1980–86 (National Energy Board 1991*b*). An increased use of petroleum products is partly responsible for this recent rise in CO$_2$ emissions.

Despite Canada's relatively low production of CO$_2$ per unit of energy consumed, the amount of energy production is high in comparison with Canada's small population and economy (Fig. 12.13). On a per capita basis, Canada is second among the industrialized countries of the Organisation for Economic Co-operation and Development (OECD) and sixth in terms of emissions per unit of GDP (Organisation for Economic Co-operation and Development 1991). Further reductions in total CO$_2$ emissions will depend on progress in energy efficiency, conservation, the development of renewable energy sources, and technological solutions to capturing CO$_2$ emissions at source.

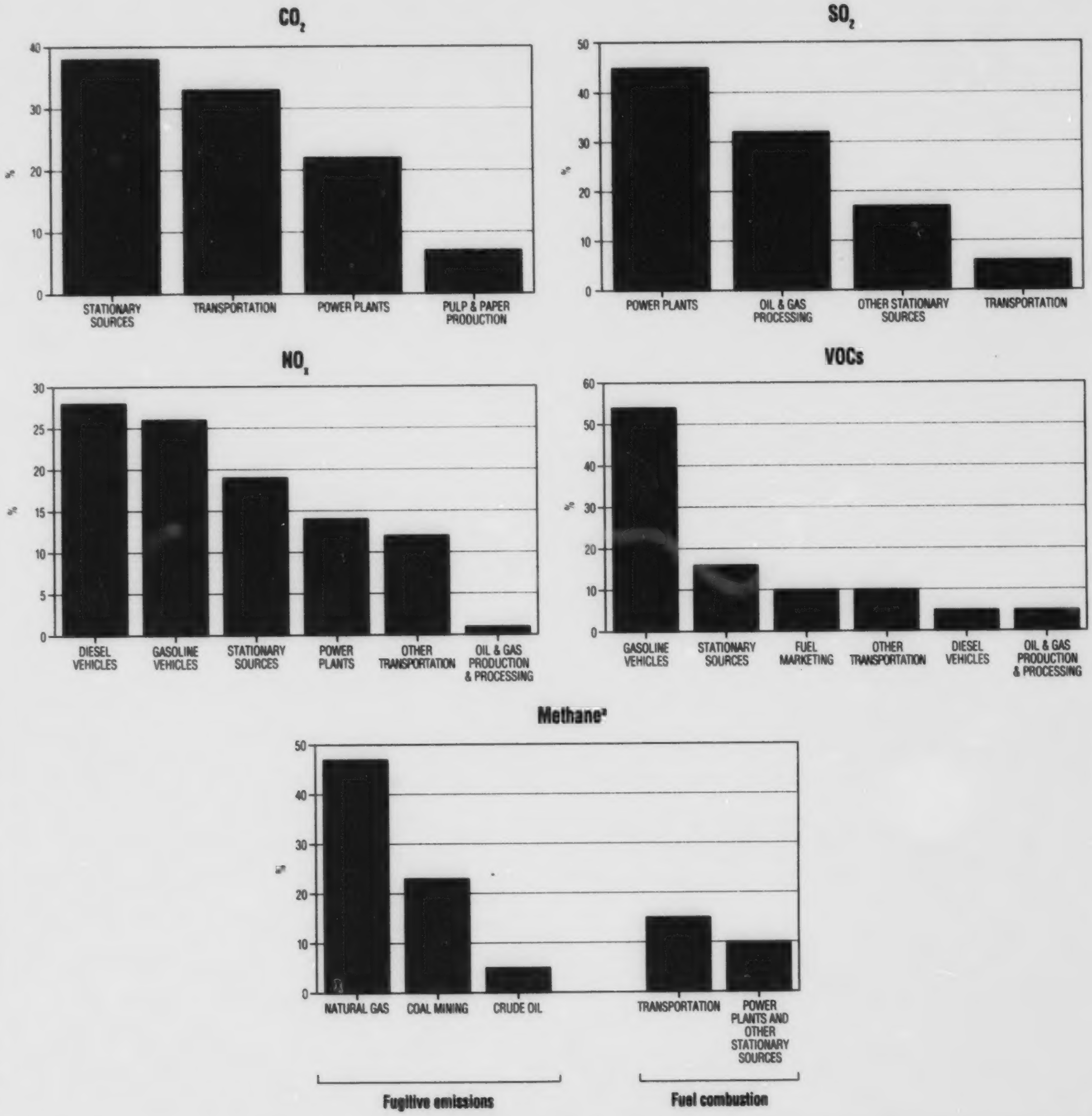
As further growth in energy demand is expected under a "business as usual" scenario, Canada could expect continued growth in greenhouse gas emissions through the 1990s, with CO$_2$ emissions rising at an average annual rate of 1.6% from 1990 to 2000. Under this scenario, total emissions in 2000 would be 17% above their 1990 level (Energy, Mines and Resources Canada 1990*a*). Therefore, a cap in CO$_2$ emissions at 1990 levels would result in a reduction in forecast emissions in 2000 of 17%. The required reduction in energy demand to meet such a target will be more or less than 17% depending on the mix of fuels being saved (Energy, Mines and Resources Canada 1990*a*).

Canada, with its vast land mass, ecological diversity, and low population density, may be able to accommodate the environmental changes induced by global warming more easily than many other countries. Even so, the risks posed by an uncontrolled warming of the global climate are just as serious for Canada as they are for the world as a whole (Government of Canada 1990). Furthermore, the interconnectedness of the world's ecological, economic, and sociopolitical systems suggests that Canada will also be affected by climatically induced changes occurring elsewhere on the globe.

At present, there are no regulated limits or schedules to stabilize emissions of CO$_2$ and other greenhouse gases. However, the government has committed itself to stabilizing emissions of CO$_2$ and other greenhouse gases at 1990 levels by the year 2000. The federal and provincial governments are developing

FIGURE 12.10

Canadian energy-related sources of CO_2, SO_2, NO_x, VOCs, and methane, 1985



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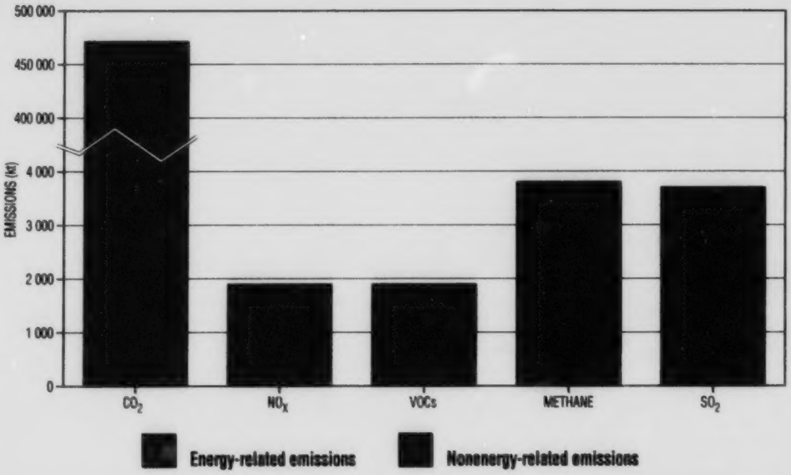
[a] Estimate for methane sources is for 1987.

Source: Jaques (1990, 1991); Kosteltz and Deslauriers (1990).

FIGURE 12.11

Canadian energy-related emissions of gases from human-made sources [a]



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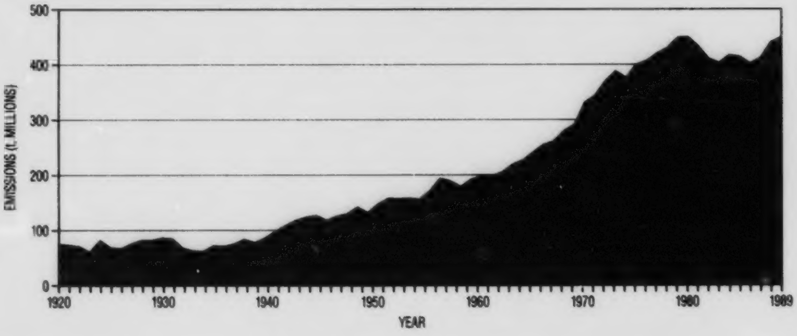
[a] The emissions estimates represent recent data from Environment Canada (Jaques 1990, 1991; Kosteltz and Deslauriers 1990). These estimates represent the results of calculations using various models, rather than actual measurements.

Source: National Energy Board (1991*b*).

FIGURE 12.12

Canadian energy-related emissions of CO_2, 1920–89



Source: Indicators Task Force (1991).

a National Action Strategy on Global Warming that considers a three-part approach to climatic change issues:

- to limit net emissions of greenhouse gases;
- to anticipate and prepare for the potential effects of any warming that might occur; and
- to improve scientific understanding and increase predictive capability with respect to climatic change (Canadian Council of Ministers of the Environment 1990*a*).

Actions directed towards the reduction of NO_x and VOC emissions will be discussed in the following section on ground-level ozone.

In the key area of setting limits to emissions of greenhouse gases, the strategy will focus on improving energy efficiency and promoting the shift to less carbon-intensive alternative energy sources. Other aspects designed to limit gases include afforestation, changes in agricultural practices, and phasing out CFCs. The strategy proposes individual federal, provincial, and territorial actions, as well as bilateral agreements with the federal government.

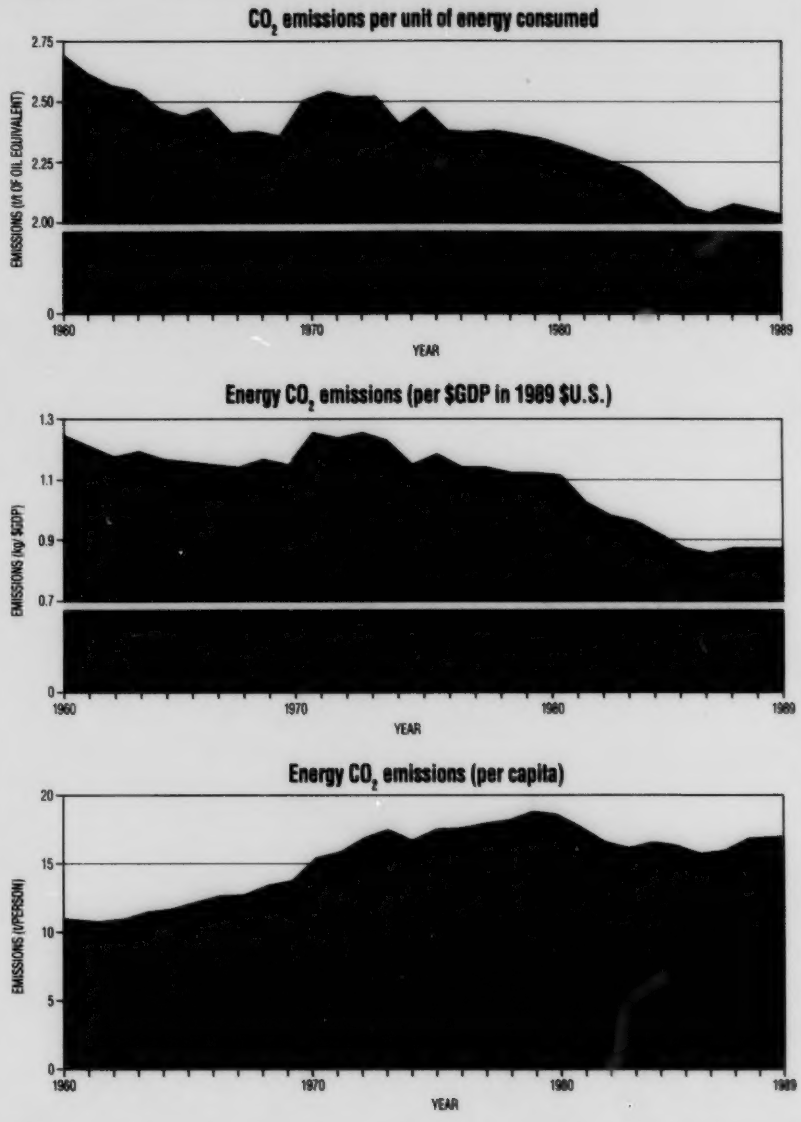
Globally, Canada will pursue negotiations for an International Framework Convention on climatic change and the adoption of appropriate binding protocols by 1992. As part of the convention, it will seek agreement on targets and schedules for the reduction of emissions of CO_2 and other greenhouse gases. Current commitments of various national governments to a reduction of their countries' contributions to world emissions of CO_2 and other greenhouse gases are listed in Table 22.8 (Chapter 22).

Acidic deposition

Emissions of SO_2 and, to a lesser extent, NO_x from metal smelting and fuel combustion are the main cause of acidic deposition. It is estimated that acidic deposition (more commonly called "acid rain") causes $1 billion in damages annually to the forestry, tourism, and agriculture industries in eastern Canada (Government of Canada 1990). It is also estimated that over 15 000 lakes have already been acidified from acidic pollutants and about 15 million hectares of hardwood and mixed forests have suffered decline and diebacks from a variety of factors, foremost among which is acidic deposition. The corrosion rates of monuments, buildings, and materials are closely correlated with acidic deposition, and acid rain is thought to contribute to respiratory problems such as bronchitis and asthma (see Chapter 24 for a full assessment of the impacts of acidic deposition).

FIGURE 12.13

CO_2 emissions and energy consumption, 1960–89



Source: Indicators Task Force (1991).

Overall, Canadian SO_2 emissions have fallen 45% between 1970 and 1985, from 6.7 million tonnes to 3.7 million tonnes (Kosteltz and Deslauriers 1990). Estimated SO_2 emissions in 1987 were 3.01 million tonnes (Federal/Provincial Research and Monitoring Coordinating Committee 1990). Most of the drop to date is due to stricter controls at metal smelters (see Chapter 11). Because of prevailing winds, more than half of the acidic deposition in eastern Canada is from acid gas emissions in the United States.

Energy-related emissions amounted to 1 614 kt of SO_2, or about 44% of total Canadian emissions in 1985. The combustion of fossil fuels in transportation and stationary sources (e.g., power plants, refineries, and industry) releases 1 112 kt of SO_2, or 30% of the Canadian total, and the recovery and processing of oil and natural gas result in the rest. Of this, power generation (mainly coal-fired electricity) accounts for an estimated 738 kt, or 20% of all SO_2 emissions (Fig. 12.14). None of these figures includes SO_2 emissions at the wellhead(Kosteltz and Deslauriers 1990).

Eastern Canada accounts for 585 of the 738 kt of SO_2 released in Canada by power generation. These emissions are primarily from power plants in Ontario, New Brunswick, and Nova Scotia. In the provinces of Saskatchewan, Alberta, and British Columbia, SO_2 emissions result primarily from oil and gas production, metal refining, and coal-burning power plants.

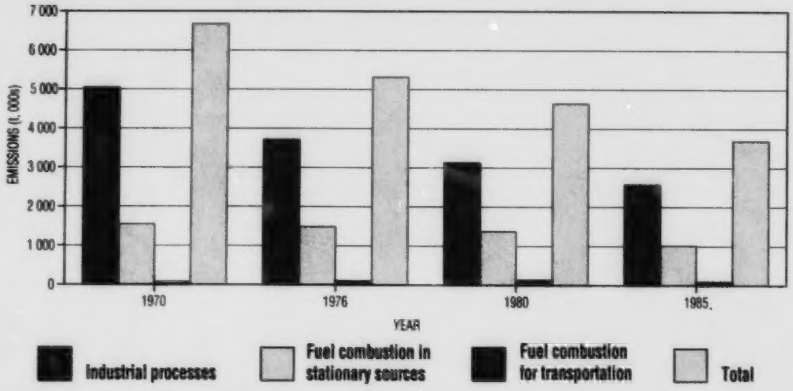
Figure 12.15 summarizes SO_2 emissions from eastern Canada and NO_x emissions from all Canada for the period 1970–85, with projections to 1994. The bottom figure compares Canadian and U.S. emissions. NO_x emissions, although a contributing factor to the acidity of precipitation, are not considered to be a major cause of acidification of surface waters in eastern Canada (Federal/Provincial Research and Monitoring Coordinating Committee 1990).

In response to the more acute acidic deposition problem in the east, the Canadian government and the seven provinces east of Saskatchewan initiated the Eastern Canadian Control Program for emissions of SO_2 in 1985 and established specific targets and timetables in 1987 and 1988. The program set an overall target of 2 300 kt of SO_2 emissions by the end of 1994, a decrease of about 50% from the 1980 baseline level of 4 516 t (Federal/Provincial Research and Monitoring Coordinating Committee 1990).

The control efforts have been directed at the major sources, such as the nonferrous metal smelters and fossil fuel burning power plants, where the largest

FIGURE 12.14

SO_2 emissions in Canada, 1970–85



Source: Environment Canada (1986); Kosteltz and Deslauriers (1990).

and most cost-effective reductions can be achieved. The 1987 data on SO_2 emissions, the most recent published, indicate that about 65% of the program target of reducing emissions to 2 300 kt has already been achieved (Environment Canada 1991). The bulk of the commitment has been achieved at the six large metal smelters and one iron ore sintering plant. However, the three provincial electrical utilities of Ontario, New Brunswick, and Nova Scotia are responsible for implementing a major portion of the program (Table 12.5). Ontario Hydro, for example, is required to cap its annual SO_2 emissions at 175 kt by 1994, a 60% reduction from peak emissions levels.

Ontario Hydro has reduced its SO_2 emissions by relying on nuclear power instead of coal-fired electricity, by burning low-sulphur fuel, and, in some instances, by imports. The productivity of Ontario's nuclear reactors has declined in the past few years, and, despite early conservation efforts, loads have continued to increase. Ontario Hydro has therefore opted to install flue gas desulphurization systems beginning with the scrubbers by 1994 at Lambton. In the interim, flue gas conditioning equipment is being installed at Lambton and Nanticoke to allow the use of very low-sulphur coal. Both New Brunswick's and Nova Scotia's plans include increased use of low-sulphur coal and the construction of state-of-the-art facilities: the Belledune power plant in New Brunswick equipped with a scrubber, and the Point Aconi fluidized bed plant in Nova Scotia, facilities that will remove over 90% of SO_2 emissions.

Although the desulphurization of power plant flue gases improves air quality, it creates a potential waste management problem. Ontario Hydro estimates that flue gas desulphurization at one of its thermal stations alone will lead to the production of 200 000 t of gypsum per year starting in 1994. Ontario Hydro is attempting to market this gypsum to North American wallboard producers. As well, coal combustion at thermal power stations leads to the accumulation of large amounts of coal ash, over 1 million tonnes in 1989 for Ontario Hydro. The utility sells about a quarter of this ash as a raw material in cement manufacture or for road construction. The rest is landfilled (Ontario Hydro 1990).

Under the Canada/U.S. bilateral Air Quality Accord, Canada agreed to achieve a national cap of 3.2 Mt of SO_2 per year by the year 2000. The federal and provincial governments have begun negotiations on an expanded program of SO_2 controls to replace the current agreements after 1994.

Ground-level ozone

Ground-level ozone, a major component of urban smog, is one of the more serious air quality problems in Canada today. Ground-level ozone is caused by two precursor pollutants, NO_x and VOCs, reacting in the atmosphere in the presence of sunlight.

Although the problems associated with ozone are usually most severe in urban areas, ozone is not just an urban problem. Large rural areas beyond the boundaries of urban centres are affected as ozone, NO_x, and VOCs are transported downwind from sources. In summer, more than half of all Canadians are routinely exposed to ozone levels that are known to have adverse effects on health. Exposure to elevated ozone levels is most severe in the Lower Fraser Valley of British Columbia, the Windsor–Quebec City corridor in Ontario and Quebec, and the southern Atlantic region (Saint John, Halifax). Ozone is also known to cause significant damage to agricultural crops and other forms of vegetation in parts of Canada (Canadian Council of Ministers of the Environment 1990*b*).

Fossil fuels from the energy sector are the source of 95% of the NO_x and 60% of VOC emissions (see Fig. 12.10). Between 1970 and 1985, NO_x emissions rose about 43% because of an increased energy demand for transportation.

NO_x are released primarily during the combustion of fossil fuels. VOCs are released during production, transport, storage, and the combustion of petroleum fuels, from various industrial processes, and from the evaporation of solvents and organic chemicals. Although NO_x and VOCs are derived from many different sources, gasoline and diesel vehicles together account for 54% and 59% of the emissions, respectively (see Fig. 12.11).

Nationally, both NO_x and VOC emissions are projected to grow by about 6% between 1985 and 2005, if no new controls are put in place (Canadian Council of Ministers of the Environment 1990*b*). The transportation and electricity-generating sectors (in those cases where fossil fuels constitute the marginal source of supply) represent the major opportunities to reduce these emissions. Another factor in determining which source sectors to control is the variation between regions in the contribution of NO_x or VOC emissions from given sectors.

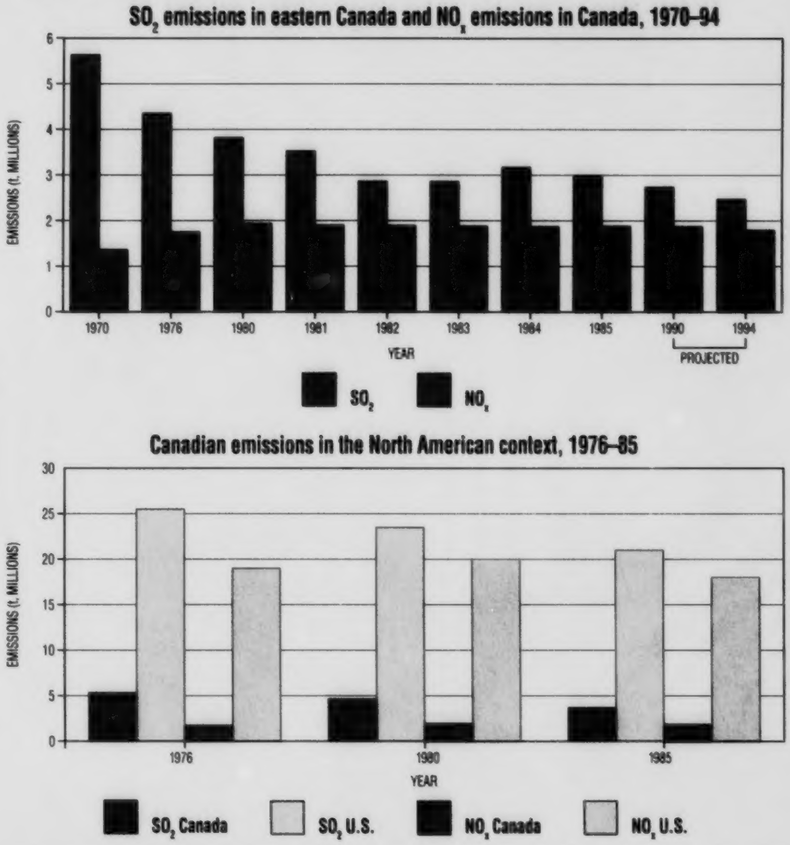
In 1990, the Canadian Council of Ministers of the Environment released a management plan for NO_x and VOCs outlining the first phase of a three-phase control program aimed at resolving ground-level ozone problems by the year 2005. It consists of three primary components:

1. A national prevention program based on application of the best-available control technology economically achievable (BACTEA) to new mobile and new stationary sources of NO_x and VOCs.
2. Interim (1995 and 2000) NO_x and VOC emission reduction targets for three designated ozone nonattainment areas: the Lower Fraser Valley, the Windsor–Quebec City corridor, and the Saint John area, to be negotiated in federal–provincial agreements.
3. A program of studies and investigations aimed at providing the information needed to set final NO_x and VOC emission targets for ozone nonattainment areas for the years 2000 and 2005 (Canadian Council of Ministers of the Environment 1990*b*).

By the year 2005, national NO_x and VOC emissions are expected to be 11% and 16% below 1985 emission levels, respectively, with emission reductions of about 25–40% in the more serious ozone nonattainment areas.

FIGURE 12.16

SO_2 and NO_x emissions



SO_2 emissions in eastern Canada and NO_x emissions in Canada, 1970–94

Canadian emissions in the North American context, 1976–85

Source: Indicators Task Force (1991).

Under the Canada/U.S. Air Quality Accord signed in 1991, NO_x emissions will be reduced in both countries by controls on stationary sources (NO_x emissions from Canadian stationary sources will be reduced to by 100 kt below the year 2000 forecast level of 970 kt and the implementation in the mid-1990s of more stringent standards for vehicle emissions.

Land uses

Conventional oil and gas development

In 1986, Alberta and Saskatchewan produced 96% of Canada's crude oil; Alberta alone produced 82%. A similar situation applies for natural gas. In the late 1980s, about 87% of Canada's natural gas was produced by Alberta; British Columbia and Saskatchewan together produced a further 12% (Swatridge and Wright 1990). To date, over 130 000 exploration and development wells have been drilled in Alberta (Reclamation Research Technical Advisory Committee 1991).

Canada's proven light oil reserves, located almost entirely in Alberta, Saskatchewan, and British Columbia, peaked in the late 1960s and have been declining ever since. Their continued production will require more intensive development of existing fields, including closer well spacing and reinjection facilities. As producing fields gradually

TABLE 12.5

SO_2 emissions (in kilotonnes) and limitations: power generation in eastern Canada

Province	1980 (baseline)	1985	1987	Utility 1994 emissions limits
Manitoba	2.8	3.5	4.0	
Ontario	397.8	337.0	332.0	175
Quebec	1.3	0.4	–	
New Brunswick	122.3	94.0	158.0	130
Nova Scotia	125.2	130.0	135.0	160
Prince Edward Island	2.0	2.0	3.0	
Newfoundland	18.0	22.0	20.0	
Total eastern Canada	**669.4**	**588.9**	**652.0**	

Note: In Manitoba and Quebec, thermal electricity generation is not a major source of SO_2 emissions. In Prince Edward Island and Newfoundland, power generation emissions are variable, depending on the need for thermal generation in-province. 1987 emission figures are taken from provincial reports prepared as part of the federal–provincial agreements.

Source: Environment Canada (1991).

become depleted, Canada will increasingly come to rely on smaller and harder-to-find fields of light crude, nonconventional (heavy oils and tar sands), and frontier (offshore and arctic) reserves for its domestic supplies. Figure 12.16 illustrates the supply situation since 1980 with a projection to the year 2010. It indicates an increasing reliance on nonconventional and frontier reserves to make up the Canadian oil supply.

Although nonconventional reserves are known to be very large and the frontier potential sizeable, they have remained largely undeveloped because exploration, drilling, and transportation are expensive, and their development raises significant environmental and social concerns.

The development of the Hibernia oil field off Newfoundland (to start production in 1996), Beaufort Sea oil, Mackenzie delta gas, and the construction of a new tar sand mining operation all require multibillion-dollar investments. Projects such as these often raise major environmental concerns. Three factors prompt these concerns:

1. Less is known about arctic and offshore environments, where these projects will increasingly be located, than about more temperate zones. As a result, it is more difficult to predict environmental impacts and design appropriate mitigative strategies.
2. Projects undertaken in such "frontier" regions often push the limits of proven technology. They need to confront hostile environmental conditions (e.g., the presence of ice in the case of offshore drilling) for which there is often only limited engineering experience.
3. Because they are undertaken in remote regions, projects like this may require the construction of an extensive infrastructure including roads, airstrips, wharves, communications centres, construction camps, and power generation. Unless properly controlled, the environmental effects associated with this infrastructure (e.g., increased pressure on wildlife) can be significant.

All energy projects that receive federal financial assistance, that affect an area of federal government responsibility, or that are undertaken on land administered by the federal government (including the offshore) are subject to the Federal Environmental Assessment and Review Process (Federal Environmental Assessment Review Office 1987). The process is the basic planning tool for predicting potential environmental consequences of these project proposals. This allows unwanted effects to be identified and mitigated or the opportunity to alter or abandon plans if major negative effects cannot be moderated.

All producing provinces have legislation to control the four phases of oil and gas drilling — exploration, development, production, and abandonment. Each phase may affect the environment in a different manner.

The environmental implications of drilling for petroleum tend to be local and are most often minor, although their cumulative impact can be significant. In some cases, however, even a limited exploration and development program may threaten sensitive wildlife habitat, primarily by facilitating human entry into previously inaccessible areas. This threat is particularly acute where these activities coincide with a critical time of a species' life cycle. Oil spills, the disposal of toxic chemicals used in drilling ("muds"), soil compaction, the use of soil sterilants and herbicides, and the accidental release of "sour" gas (i.e., natural gas containing sulphur) are other environmental stresses associated with petroleum development. The construction of the extensive infrastructure of roads, seismic exploration lines, well sites, pumping stations, pipelines, processing plants (for gas), and camps required to develop oil and gas fields imposes additional environmental stresses (see Box 12.2).

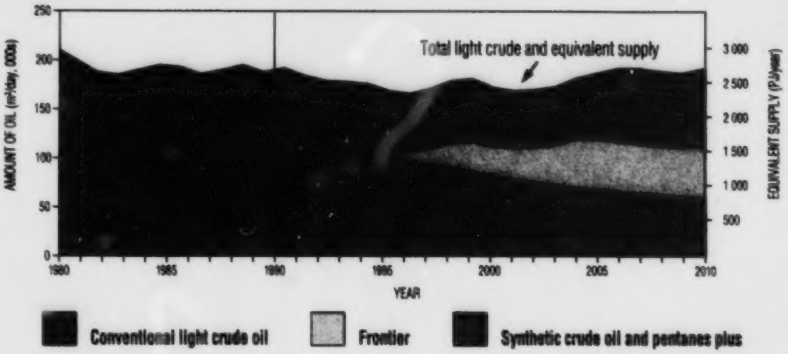
The conventional methods of disposing of drilling wastes are by burying, trenching, squeezing, and spreading. Each method may affect the environment in different ways. For example, trenching or burying of wastes is likely to have less impact on soils and plants than is spreading those wastes on the surface (Reclamation Research Technical Advisory Committee 1991).

Soil sterilants (residual herbicides that render the treated soil unfit for plant growth for relatively long periods of time) are used at well sites, along rights-of-way, and on other industrial areas for total vegetation control. Depending on the type and rate of soil sterilant used, as well as the soil and climatic conditions, the treated areas can remain unvegetated for many years (Reclamation Research Technical Advisory Committee 1991).

In addition to the foregoing environmental stresses, oil and gas activities have a direct impact on the land surface. For example, in Alberta, oil and gas activities (excluding seismic lines) had disturbed about 2 300 km² or 0.003% of Alberta land area by 1990 (C. Powter, Alberta Environment, personal communication). Corresponding figures are unavailable for the other producing jurisdictions.

FIGURE 12.18

Light crude oil and equivalent supply, 1980–2010



Note: Data are cumulative.

Source: National Energy Board (1991*b*).

Heavy oil and oil sands

The term "oil sands" encompasses deposits of sand and sandstone that contain a high concentration of bituminous hydrocarbons and from which oil can be recovered by heating or other extraction processes. All the mineable tar sand deposits in Canada are located in northern Alberta. The two commercial mining operations located there account for 12% of Canada's oil production.

In addition to the known environmental problems encountered in the recovery of conventional deposits, oil production from bituminous sands gives rise to additional concerns associated with the mining techniques employed. One technique consists of surface mining, where the tar sand is mined and transported to a processing plant. Once there, the bitumen is extracted using hot water and the sand residue is then disposed of.

Such mining operations lead to widespread land disturbance because of the very large quantities of sand that need to be mined: 12 t of sand must be processed on average to produce 1 m³ of oil. In addition, the extraction of the oil from the tar sand requires very large volumes of water. Because this water becomes heavily contaminated, it cannot be returned to the source from which it is drawn, and it must be stored in a tailings pond. At the end of its 25-year life, it is estimated that a typical oil sands plant producing 19 900 m³/day (125 000 barrels/day) of synthetic crude oil would require a tailings pond of 22–31 km², containing some 360 million cubic metres of sludge. This sludge, which consists of a mixture of water, fine mineral particles, and small amounts of bitumen, is expected to remain the consistency of a thin custard for years, preventing a rapid reclamation of the land. Because the sludge also contains some metal compounds and acids, it is toxic to aquatic life, and it is necessary to isolate tailings ponds from natural water bodies. The settling pond would be impounded behind dikes of tailing sands 55–100 m above ground level (Reclamation Research Technical Advisory Committee 1991).

One of the major environmental concerns relates to the deposit of tailings sludge. There is a lack of fundamental understanding of the physical and chemical properties of the sludge. In order to study this problem, a consortium, consisting of Syncrude, Suncor, Alberta Research Council, Alberta Energy, Alberta Oil Sands Technology Research Authority, Canada Centre for Mineral and Energy Technology, and the National Research Council, was created in September 1989. The $2 million per year research effort is slated to conclude in August 1992 (Canadian Environmental Control Newsletter 1990).

Deeper tar sand deposits require an alternative mining technique — namely, the separation of bitumen using *in situ* extraction processes involving heat, solvents, emulsification, bacterial action, or thermal cracking. *In situ* mining eliminates the need to handle and process enormous quantities of bitumen-bearing materials and dispose of spent sand tailings. However, the recovery efficiency of the *in situ* method is considerably lower than that of bitumen extraction from mined tar sand.

Other impacts of tar sand mining involve effects on groundwater that are similar to those of a conventional coal mining operation. Exposed tar sand surfaces and unrecovered bitumen in processed sand where water runoff occurs are sources of paraffin-type hydrocarbons and other organic materials.

The rate at which the tar sands are exploited will depend largely on increases in world oil prices and risk-sharing between the developers and

BOX 12.2

Pipelines

Canada depends heavily on oil and gas for a major portion of its energy needs. Because the country is so vast and the population generally quite distant from the oil and gas fields, extensive pipelines are required to supply the consumers. As Canada's population grows, so too does the total length of pipelines in this vast network. In 1989, this total was so great that, if placed end to end, the major oil and gas pipelines could circle the globe over six times (Statistics Canada 1991). Natural gas pipelines alone totalled 227 000 km. Growth since 1984 increased by 23% nationally, with over half the increase being in Alberta and Saskatchewan (Fig. 12.B1). In 1989, there were 35 000 km of crude oil pipelines, a 10% increase since 1984, again with the major increase in Alberta and Saskatchewan (Statistics Canada 1991).

Although oil and gas pipelines have major benefits to the places they service, they generally have limited benefits to the area that they pass through. Oil and gas pipelines, like other linear developments, have the potential to cause negative environmental impacts during both their construction and operation. During construction, the primary concerns are the loss or compaction of topsoil, the stripping of vegetation over the right-of-way, siltation of rivers at crossings, the excavation of large quantities of gravel, and the disturbance to wildlife or alteration of their habitat as a result of construction activities. For the 800 km of pipeline between Sarnia and Montreal, for example, despite the small diameter of the pipe itself, over 15 000 ha of land were disturbed (Culley *et al.* 1981).

The main environmental concerns with regard to operating pipelines are oil leaks and high-pressure gas explosions. For example, since 1960, there have been about a dozen major failures in the TransCanada Pipeline, half of which involved explosions (Gotlieb 1991).

There are additional environmental risks associated with the construction and operation of pipelines in areas of permafrost. For construction, it is essential to ensure that a pipeline does not lead to either permafrost melting, especially of concern when it has a high ice content, or additional freezing, either of which could buckle and break the line, leading to a spill. Pipeline corridors in any part of the country may also facilitate access to wildlife habitats, leading to mortality due to increased hunting or trapping pressure as well as disturbance and resultant abandonment of habitat.

Under most jurisdictions, it is a requirement that pipelines be buried, and so the land in the corridor right-of-way can often be returned to its prime use after construction. Reclamation policies have steadily been upgraded since the early 1960s, and now procedures aim to restore disturbed land to its original fertility (Spearman 1981). With proper operational controls and careful planning, most disturbances can be reclaimed to their natural state. As well, pipelines are routinely monitored for leaks during operation by light aircraft and helicopters.

governments. An important environmental consideration in regulating future tar sand projects will be the cumulative effect of industrial activities, including pulp and paper development, in the Athabasca River basin.

The Canadian deposits of heavy oil are concentrated in an area surrounding Lloydminster in Alberta and Saskatchewan. Oily wastes from heavy oil operations are normally disposed of in pits designed to temporarily store oil and other wastes. Material disposal from these pits includes treating and selling oil, disposal of water in deep injection wells, and use of sludge as road dust suppressant and dike construction material (Saskatchewan Environment and Public Safety 1991).

Coal mining

Canada has vast coal resources, with the most extensive reserves being concentrated in the three western provinces. Smaller reserves in Nova Scotia and New Brunswick have been sources of metallurgical and thermal coal since before Confederation, and deposits in these provinces are currently being mined, primarily for thermal coal. As might be expected, the coal mining industry is concentrated in western Canada, with 15 major operating companies producing 66.5 million tonnes of coal from 23 mines. In eastern Canada, two major companies produce a combined total of approximately 4 million tonnes annually from four mines (Coal Association of Canada 1989; Energy, Mines and Resources Canada 1991*c*).

It is unlikely, however, that there will be any significant expansion in new mine projects in the near future. At the end of 1989, 11 proposed western coal mine development projects with a total annual capacity of 27.3 million tonnes were on indefinite hold pending improved market conditions (Coal Association of Canada 1989). All of these projects are subject to multistage provincial environmental reviews prior to the start of mining operations. In eastern Canada, the Lingan mine in Nova Scotia is to be closed down soon.

Coal mining, preparation (physical cleaning to remove mineral matter and inorganic sulphur), and transportation activities can have impacts on the environment by disturbing land surfaces, wildlife habitats and migration patterns, surface water and groundwater quality, and local air quality. However, a great deal of progress has been achieved in addressing the impacts of coal mining since the beginning of the 1970s, when confrontations between citizen groups, government agencies, and members of the industry over operating practices and new mine proposals were prominent.

The most significant impacts are the land disturbances caused by surface mining in the western provinces. Through mine planning and concurrent reclamation programs, however, the industry has been generally successful in restoring strip mined lands in the prairies to acceptable and, in many instances, premining conditions. In 1989, 42% of the previously stripped land (16 197 ha) had been reclaimed in Alberta and Saskatchewan (see Table 11.7, Chapter 11).

Open pit mining operations in the mountains and foothills of Alberta and British Columbia create not only massive waste rock piles in narrow valleys and on steep slopes but also deep and often irregularly shaped open pits from which the coal is extracted. As a consequence, the stabilization of waste rock piles and visual amelioration of open pits through back filling, grading, and revegetation have proven to be both challenging and costly because of the steep erodible slopes, instability of waste dumps, droughtiness, short growing seasons, and lack of soils and nutrients. These factors have often contributed to slow or limited progress in reclamation. In 1989, 44% of the 17 374 ha of open pit coal mines in British Columbia and Alberta had been reclaimed (see Table 11.7, Chapter 11). Although wildlife habitats have been successfully reestablished in these areas, many of the premining land surface features cannot be recreated; thus, in spite of reclamation projects that can soften their visual impacts, many aspects of the physical changes caused by open pit mining operations are permanent.

Progress in reclaiming mine disturbances at eastern Canadian coal mine sites is hampered by the presence of acid-generating wastes resulting from the higher sulphur content (see Chapter 11). In New Brunswick, 31% of the 8 100 ha of disturbed land have been reclaimed.

Wastewaters from western Canadian coal mines and preparation plant tailings ponds must, as a minimum, meet provincial standards for suspended solids, iron, pH, and turbidity. As the sulphur content of all western coals, with the exception of small deposits on Vancouver Island, is generally less than 0.5%, acid mine drainage and dissolved metals in wastewaters are not a problem in this region. Elevated ammonia and nitrogen levels caused by the use of ammonia-based blasting agents in open pit mines in eastern British Columbia, however, have raised concerns with respect to receiving water quality and the protection of aquatic biota. The federal government and a British Columbia coal mining company have conducted a research project, under the Panel for Energy Research and Development program, which indicates that these wastewaters can be effectively and economically treated in an "engineered wetland" system to reduce their total nitrogen content to levels that will not have adverse effects on aquatic biota (Norecol Environmental Consultants Ltd. 1990).

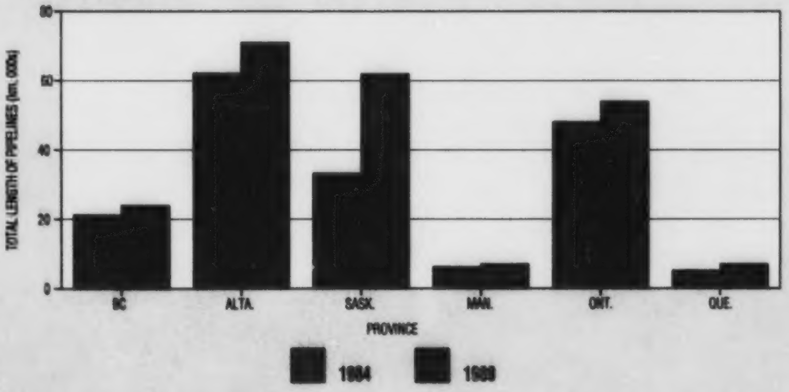
As the coals in Nova Scotia and New Brunswick contain from 2.0 to over 6.0% sulphur, wastewaters from mines and the one preparation plant in Atlantic Canada, which do not discharge directly to the ocean, are treated to neutralize acidity and to precipitate heavy metals such as arsenic and zinc prior to discharge to natural receiving waters.

Although water supply problems have not been experienced to date by coal mine/electric power generation complexes in the traditionally water-short area of southern Saskatchewan and Alberta, the potential for competition for water between these complexes and agriculture exists if future mines and power plants are developed in the Oldman–Red Deer drainage basins of southern Alberta and the Souris, Poplar, Swift Current Creek, and Frenchman river subdrainage basins of southern Saskatchewan (Barrie and Carr 1988).

Air pollution concerns with respect to coal transportation from the mine site have centred on local "dusting" problems along the railway lines between the mines in the interior of British Columbia and Alberta and Pacific coast ports, and at the transshipment facilities in British Columbia and Sydney, Nova Scotia. These have been addressed by the practice of spraying the coal in the railway cars with latex-based sealants at the mines and through the use of water

FIGURE 12.11

Natural gas pipelines, 1984 and 1989



Source: Statistics Canada (1991).

sprays and modified coal pile configurations at the west and east coast coal terminals.

Oil releases into the environment

The need to transport oil from producing areas to markets leads to oil spills. These spills can be either on land or into water and can have a variety of environmental, social, and economic impacts. This section examines both marine and nonmarine (land and inland water) spills.

Marine spills

The flow of petroleum into the world's oceans is thought to be in the order of 6 million tonnes per year (Izrael 1987), although estimates vary considerably. In decreasing order of importance, the human contribution to petroleum pollution of the oceans comes from tanker transport (operations and accidents), municipal and industrial wastewater discharges and runoff, atmospheric fallout (from petroleum that has evaporated into the atmosphere), refinery wastewater, and offshore exploration and production (National Academy of Sciences 1985).

According to the findings of the Public Review Panel on Tanker Safety and Marine Spills Response Capability (1990), based on current tanker traffic levels, Canada can expect each year over 100 small oil spills (less than 1 t), 10 moderate spills (1–100 t), and at least one major spill (100–10 000 t). A catastrophic spill (over 10 000 t) is likely once every 15 years. That report also pointed out that the risk of spills is highest in eastern Canada, particularly Newfoundland. Placentia Bay, Newfoundland, is considered by many to be the most likely place in Canada for a spill.

Despite the greater profile of accidental spills, it is routine tanker operations — loading and offloading, tank washings, wastewater discharges — that are responsible for a much greater volume of oil entering the marine environment (Public Review Panel on Tanker Safety and Marine Spills Response Capability 1990).

In the immediate and short term, major spills can endanger the health, economic, and social well-being of Canadians. In addition to the observable environmental damage, which may be considerable, little is known about the long-term or cumulative effects of major oil spills.

> "The fact that we do not really know what we are doing to our environment, and therefore to ourselves, seems to us to be one of the more frightening aspects of the problem.
>
> There can be no latitude for complacency about spills. Once a major spill occurs, the integrity of the natural environment is put at serious risk. All discussions about oil and chemical spills must take into account the damage that can result — even in the short term.
>
> The environmental, social and economic consequences of spills can be devastating. Oil or chemical spills can destroy the microscopic organisms that anchor the food chain, causing extensive damage to marine ecosystems. They can seriously reduce fish stocks, either directly, or by damaging spawning areas. Waterfowl, typically the first, and most visible, casualties of spills, are especially vulnerable. Countless species of wildlife, from seals and otters to whales and polar bears, may be severely affected. In some instances, either the incident itself or the subsequent clean-up may place entire species of birds at risk of extinction if it occurs during moulting season or interferes with migration patterns. Spills can coat shorelines for years ruining a region's tourism potential" (Public Review Panel on Tanker Safety and Marine Spills Response Capability 1990).

Oil spills, and their impact on various ecosystems, are discussed in other chapters of this report, including Chapters 4, 6, and 15. Chapter 6 notes that chronic pollution from frequent minor spills can be just as hazardous to wildlife as large spills that occur infrequently.

It is difficult to interpret statistics about oil spills because of the trend to report increasingly smaller spills and wide annual variations in volume caused by one or two large spills. Also, incomplete data make it impossible to accurately predict trends in marine spills.

Nonmarine spills

Oil spills on land tend to be of lesser concern than spills at sea because they are easier to contain and also tend to be smaller: a pipeline rupture, for example, releases oil more slowly than a breached tanker. Nevertheless, land spills do impose environmental costs. Depending on where they occur, they can contaminate surface water or groundwater, destroy vegetation, kill birds and fish, and cause property damage.

Flowline breaks, or wellhead or battery equipment malfunction, can cause oil and saltwater spills in the field. Line breaks can cause oil spills along transmission lines (Saskatchewan Environment and Public Safety 1991).

Spills of oil and salt water are the main environmental concerns associated with oil production and transportation. Water produced in association with oil is extremely salty. It can damage soil and kill vegetation. The common practice is to store it in tanks before injecting it back into oil reservoirs where it helps maintain pressure (Manitoba Department of Environment 1991).

Between 1985 and 1988, 9 129 land spills were reported in Canada. The production field was the source of 42% of these spills. Pipelines were the next most common source (29%), followed by tank trucks (18%), transport trucks (6%), trains (3%), and other motor vehicles (2%) (G. Cloutier, EnvironmentCanada, personal communication).

Management response

In December 1988, the tug *Ocean Service* struck the barge *Nestucca* off the coast of Washington State, resulting in a 875-t oil spill that affected the west coast of Vancouver Island (see Chapter 4, Box 4.1). The *Nestucca* oil spill and related events, such as the much larger (44 000 t) spill from the *Exxon Valdez* in Alaska in 1989, were instrumental in establishing the independent Public Review Panel on Tanker Safety and Marine Spills Response Capability (1990). Its report includes 107 recommendations; major recommendations concerning spill response focus on better response planning, coordination, and cooperation between industry, all levels of government, and the Canadian Coast Guard.

The Canadian Petroleum Products Institute has committed approximately $40 million (1991–93) to improve its oil spill response capability. Green Plan funding of $100 million to enhance Canada's capability to respond to marine spills was announced in June 1991. Further information on marine shipping and management responses to marine spills is found in Chapter 4.

With respect to nonmarine spills, Canada's Green Plan indicated a major program to improve national cooperative spill response and prevention capabilities (Government of Canada 1990). This includes better contingency planning, improved environmental sensitivity mapping, upgraded training, and routine testing of emergency preparedness. In cooperation with private industry and universities, the federal government has also indicated it will increase research into, and knowledge of, oil and chemical spills and promote the development of new technologies in spill detection, monitoring, and cleanup.

Electricity

The Canadian electric power industry has grown rapidly from small hydro plants serving isolated loads in the early 1900s to today's vast interconnected electric power networks with total installed generating capacity in excess of 95 000 megawatts (MW) from a variety of generating sources (National Energy Board 1991*b*). After several decades of growth in electricity demand at annual rates of about 7%, demand growth fell steadily from the mid-1970s until very recently, as a result of the slowdown in economic growth and conservation and efficiency improvement measures that accompanied the oil price shocks of the 1970s (National Energy Board 1991*b*). By the late 1970s, annual electricity demand growth rates averaged close to 3%. In 1989, electricity demand in Canada increased by 2.3% from 1988 levels. Electricity use varies greatly across the country, ranging from a high of 34% of total energy end use in Quebec to a low of 12% in the Prairie provinces (see Table 12.3).

To satisfy Canada's demand for electricity, hundreds of dams, hydroelectric stations, and power generation plants have been constructed. In 1989, about 57% of Canada's electrical power generation capacity was hydroelectric, another 30% was thermal generation, and the remainder was from nuclear generation (Statistics Canada 1991). For thermal power generation, burning coal comprised 61%, oil represented 23%, 13% was from natural gas, and the remaining 3% was derived from other fuels. Most environmental impacts of electricity use are associated with its generation and transmission (see Box 12.3). At the point of use, electricity is a clean source of energy and has little direct environmental effect.

The major public concerns associated with the combustion of fossil fuels to generate electricity have already been covered. This section will focus on those impacts arising from the production of hydro power. The first focus is on the large tracts of land that are alienated from other potential uses and the disruption of entire ecosystems by large-scale flooding. The second focus is on the disposal of radioactive wastes associated with nuclear power generation.

Hydroelectric power

Historically, Canadians have tended to make hydroelectric power their first choice for meeting electrical needs. Except for large-scale development, or "megaprojects," hydroelectric power generation is generally portrayed as leading to fewer negative impacts on the environment than many other sources of electricity. Canada is now the world's leading producer of hydroelectricity (World Resources Institute 1990), and there are currently about 400 hydroelectric stations in Canada, with a combined capacity exceeding 60 000 MW (Energy, Mines and Resources Canada 1991*a*). Thus, hydroelectric developments play a significant role in shaping the environment in many parts of Canada. By virtue of extensive experience with hydroelectric development and the directness and visibility of many of the associated impacts, the major environmental implications of hydroelectricity are relatively well corroborated. Even so, predictive accuracy about the magnitude and duration of impacts that will be associated with major northern hydroelectric development is still weak.

Several major rivers have been diverted from one watershed into another since the early 1970s to boost hydroelectric production, including the diversion of the Churchill River (via Southern Indian Lake) into the Nelson River basin in Manitoba (1976), the diversion of three rivers into the La Grande for the James Bay project in Quebec (1980–83), and the diversion of three rivers into the Churchill River in Labrador (1971). The amount of water transferred between basins within Canada is greater than the combined water transfers of the next two leading countries — the United States and the Soviet Union (Pearse *et al.* 1985). Almost all (96%) of the water diverted is to serve hydroelectric generation, and 42% of it occurs in Quebec.

Hydroelectric projects generally greatly affect hydrological regimes. For example, spring and summer discharge at the entrance to the Gulf of the St. Lawrence has been cut by 30–50% over historic levels (Ministère de l'Environnement du Québec 1988) because of the quantities of runoff waters being held back in

BOX 12.3

Transmission lines

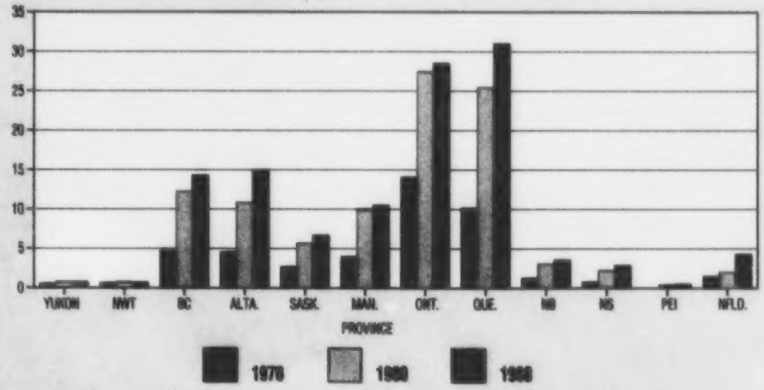
Transmission lines are the wires and supporting structures that conduct electricity from its source of production to where it is ultimately used. Through most of the distance transmitted, the electricity passes through high-voltage lines (i.e., 100 kV and over). Figure 12.B2 shows the length of transmission lines of 100 kV and over for each of the provinces and territories in 1970, 1980, and 1988. In 1988, this total for the country as a whole was 118 000 km, which represents an increase of 16% between 1980 and 1988 (Statistics Canada 1991). The principal concerns with respect to transmission lines are aesthetics and the potential human health risk for certain forms of cancer from electric and magnetic fields emanating from high-voltage lines. Evidence of such a link remains inconclusive (Manitoba Department of Environment 1991), but Manitoba, Ontario, and some other provinces continue to conduct research in this field. Some wildlife habitats are lost or significantly altered along transmission lines, but the supporting structures have been found to provide certain opportunities. For example, in Nova Scotia in 1989, 40% of the estimated 250 active Osprey nests were on transmission line structures (Nova Scotia Power Corporation 1989). Only a handful of nests each year are felt to pose a hazard either to utility operations or to the birds themselves.

As the vast majority of transmission lines are aboveground, they require dedicated corridor rights-of-way, which can have additional impacts on the environment. For these corridors, the principal concerns are right-of-way clearing (removal of trees and other vegetation cover, surface disturbance, and construction of access roads for heavy machinery), the use of herbicides to control vegetation growth, increasing access to previously undisturbed wildlife habitat, and aesthetics. In Ontario, where transmission corridors occupy over 200 000 ha of land, Ontario Hydro has designed special narrow-based lattice towers to minimize land loss and reduce interference with farm operations. In 1989, year one of a five-year program to reduce herbicide use for brush control by 35%, a reduction of 39% was achieved (Ontario Hydro 1990).

Transmission lines conducting electricity from the main lines to the end users are of lower voltage and comprise the maze of electrical wires along highways and urban streets. In recent years, some cities have placed distribution systems underground to reduce the visual impact of these vast networks. There appears to be a growing trend across Canada in this direction, not only in larger centres, such as Montreal, but in smaller towns, industrial parks, and even some subdivisions. A recent example is Halifax, which, during the last half of the 1980s, completed the burial of wires in its historic downtown and waterfront (Nova Scotia Power Corporation 1989). The cost varies but averages 4–10 times more than aboveground distribution systems.

FIGURE 12.B2

Length of hydroelectric power transmission lines of 100 kV and over for each province and territory, 1970, 1980, and 1988



Source: Statistics Canada (1980, 1988).

reservoirs for release during low flow. Where diversions occur, some river flows are greatly reduced, and others are increased. For example, the diversion of the upper basin of the Eastmain River in northern Quebec has reduced the flow in that river to 10% of predam levels. Waters of the upper Caniapiscau basin now flow west to James Bay instead of north into Ungava Bay. In general, hydroelectric developments usually invert the patterns of seasonal flow, holding back spring flood waters in reservoirs and releasing greater flow in winter, when power demand is high.

Some of the country's reservoirs are immense. For example, the five reservoirs of the existing La Grande Phase I part of the James Bay hydroelectric project cover 11 400 km^2, of which 9 700 km^2 are flooded land. Completion of the James Bay project over the next two decades will require another 15 reservoirs covering 11 650 km^2, of which almost 6 000 will be flooded land. By then, the total water surface area of this project alone will approach Lake Erie in size (see also Chapter 3).

Both in reservoirs and downstream, fish populations frequently decline or species mix is altered because of impacts on migration corridors, spawning grounds and other habitat, and water quality. Interbasin diversions may introduce new species into a system, sometimes with drastic consequences for the existing biological community.

Reservoir shorelines can be highly erodible, and shoreline vegetation that might otherwise become established is inhibited by water level fluctuations and extended high water through the growing season. Downstream shoreline vegetation is also affected by changes in the water flow regime. Erosion and changed water flow contribute to generally high levels of sediment in reservoirs, in turn affecting many aspects of biological activity. Conversely, downstream biological communities may be deprived of the nutrients and the water flows on which they depend. Changes in water temperature within reservoirs and downriver can also affect aquatic flora and fauna. These impacts can seriously affect both aquatic and terrestrial wildlife. For example, the reduced downstream water levels caused by the 1968 construction of a dam on the Peace River in British Columbia resulted in significant structural and functional changes in the extensive and highly productive wetlands of the Peace–Athabasca delta. The consequent reduced carrying capacity was reflected in reduced populations of waterfowl and other wildlife. Concerns have been expressed that the possible future construction of the "Site C" dam on the Peace River might adversely affect the local agricultural economy downstream in Alberta.

One of the major environmental impacts of building reservoirs in the boreal forest is that bacterial action on submerged vegetation transforms naturally occurring mercury into toxic methylmercury, which then biomagnifies up the food chain. Although this effect is believed to be short term, it has major socioeconomic implications for resident aboriginal populations who depend on fish as a dietary staple.

British Columbia, Manitoba, Ontario, and Quebec are all constructing or planning the construction of large new dams in the northern parts of their territories. Quebec's plans for "James Bay II," which include the damming of the Grande Baleine River as well as the separate Nottaway–Broadback–Rupert project, are by far the most ambitious. Manitoba Hydro is preparing to build Conawapa by the year 2001, its sixth dam on the Nelson River, generating 1 390 MW. An additional 10 potential dam sites have been identified on the river system. These projects, along with Ontario's scaled-down plans to build dams on the Moose, Abitibi, and Mattagami rivers, which all flow into James Bay, are now raising concerns about the cumulative environmental effects of large-scale river damming and diversion for the ecology of James Bay. These projects, which will profoundly alter the timing and rate of flow of fresh water into James Bay, may cause changes in:

- the nature and duration of the ice cover;
- habitats of marine mammals, fish, and migratory birds;
- currents into and out of James Bay;
- seasonal and annual loads of sediments and nutrients to marine ecosystems (likely leading to lower biological productivity of estuaries and coastal areas); and
- anadromous fish populations.

Almost one-third of the water from Canada's river systems eventually drains into the Hudson and James bays.

The trend in hydroelectric development is towards big projects. Thus, most of the dams with over 1 billion cubic metres of storage capacity have been built since 1950. The largest diversions also tend to be the newest. The Churchill Falls project in Labrador, the Churchill River diversion in northern Manitoba, and the La Grande project in Quebec involve seven separate diversions and account for 66% of the total volume of water diverted in Canada. The construction of the Conawapa project in northern Manitoba and the possible construction of the "Site C" dam on the Peace River in British Columbia and the Grande Baleine project in Quebec imply that the trend towards hydroelectric megaprojects will continue.

Nuclear power

In Canada, nuclear power is produced in only three provinces, and it is generated entirely by the CANDU (Canadian Deuterium–Uranium) reactor. As of September 1991, 18 commercial CANDU reactors are operating 16 units at Pickering and Bruce in Ontario, 1 in Quebec, and 1 in New Brunswick.

Under the provisions of the *Atomic Energy Control Act* of 1946, the federal government has jurisdiction over the regulatory control of all wastes associated with the development, application, and use of atomic energy in Canada. The Atomic Energy Control Board (AECB) is the federal agency responsible for administering this act.

The major sources of environmental concern to Canadians, particularly in the province of Ontario, are questions regarding the safe operation of nuclear reactors as well as the disposal of nuclear wastes. Radiation is the main concern that most Canadians associate with the production of nuclear power. This concern led the federal government to instruct the nuclear industry to adopt stringent measures to contain and prevent releases of radioactive substances to the environment. Although the nuclear reactors in Canada have a history of safe operation, accidents at Three-Mile Island in the United States and Chernobyl in the Soviet Union, both of which used a reactor design different from that of the CANDU, have increased public concern worldwide about the safety of nuclear power.

The management and disposal of the accumulating radioactive wastes remain the key long-term problem facing the nuclear power sector. Wastes related to nuclear power generation occur in a variety of physical and chemical forms and in different class levels based on the relative radioactivity of the radionuclides that they contain. The radioactive wastes can be divided into two categories: high-level wastes and low-level wastes. Virtually all wastes, whether high-level or low-level, are temporarily stored at production sites awaiting disposal.

High-level radioactive wastes are predominantly used fuel. Uranium oxide, the fuel used in CANDU reactors, is fabricated into small pellets and sealed in metal tubes, which are then assembled in bundles. After about 18 months in the reactor, the fuel bundles need to be replaced. They are intensely radioactive, and some elements in them continue to emit radiation for tens of thousands of years (e.g., plutonium-239 has a half-life of 24 000 years). Extreme caution must be exercised to ensure that such high-level wastes do not contaminate the air, drinking water, or food. At the end of 1989, Ontario Hydro was storing about 13 000 t of used fuel bundles at special facilities at the nuclear generating station, and these wastes are currently growing by 2 000 t/year (Ontario Hydro 1990). High-level wastes are stored mainly in deep, water-filled pools at the reactor sites to cool them and shield their radiation, and a small fraction are stored dry in concrete containers. Although on-site storage is an adequate means of dealing with these wastes over the short term, eventually long-term repository will be required. In 1978, with regard to the disposal of high-level waste, the governments of Canada and Ontario directed Atomic Energy of Canada Ltd. to develop a concept for the disposal of nuclear fuel waste in deep geological formations. Atomic Energy of Canada Ltd. is investigating the concept of disposing of used nuclear fuel wastes deep in stable granite rock in the Canadian Shield (Federal Environmental Assessment Review Office 1989). They have proposed that buried radioactive materials would have to be encased in noncorrosive (titanium or copper) containers to ensure that radioactivity cannot enter the groundwater. A federal environmental review of the disposal concept has begun and is expected to be completed within five years. The review panel will not address the selection of a potential site or sites for the ultimate disposal of nuclear wastes. That will be done only after the disposal concept has been accepted as safe, secure, and desirable by both the federal and provincial governments.

Low-level radioactive wastes related to nuclear energy production include the wastes from uranium refineries and fuel fabrication plants (low-level mine and mill wastes, resulting from the extraction of uranium from its ores, are discussed in Chapter 11). In Ontario, about 1 million cubic metres of wastes from refinery and conversion operations are located in the Port Hope and Scarborough areas.

In 1986, a federal Siting Task Force on Low-Level Radioactive Waste Management was established to recommend an approach for siting a low-level radioactive waste management facility in Ontario (Siting Task Force 1990). The Siting Task Force recommended the Co-operative Siting Process, which is based on voluntary participation of local communities in a collaborative, joint decision-making manner. In the meantime, active monitoring of temporary sites is ongoing to ensure that the integrity of each site is maintained. As historic wastes are considered no longer the responsibility of the user or producer, the federal government has established a Low-Level Waste Management Office under Atomic Energy of Canada Ltd. to assume responsibility. Historic wastes were produced before the enactment of the *Atomic Energy Control Act*. These wastes were managed in a manner that would not be considered acceptable according to today's standards.

Safety in the Canadian nuclear industry is regulated by the AECB, the federal agency responsible for licensing nuclear facilities and monitoring compliance with the term of licences that it issues. The fact that there has been no serious accident with it shows good management, but the fact remains that the risk is ever-present.

The use of nuclear power gives rise to other environmental impacts as well, although these are generally felt to be of far less concern than those related to radioactivity. Nuclear plants require vast amounts of fresh water to cool the reactor, and this results in thermal water emissions when the water is returned to a water body. In Ontario, the Ministry of the Environment has set guidelines for the maximum effluent temperatures and for the permissible rise in temperature for water passing through each station (Ontario Hydro 1990). At some stations, cool lake water can be added to the effluent stream to keep discharge temperatures within the guidelines. Scientific investigations to date have indicated that thermal effects, particularly impacts on fish and other aquatic organisms, are insignificant if effluent temperatures are kept within the guidelines.

REDUCING ENERGY DEMAND AND IMPACTS

Many factors affect the level of energy use in a society. These include the climate, distances between settlements, industrial structure, urban design, the rate of economic growth, government policy, and the choice of transportation modes. However, the importance of price as a causal factor varies considerably from one application to the next and from one sector to the next.

The gradual decline in real oil prices (i.e., after inflation) during most of the 1950s and 1960s, and the failure of the market to reflect fully the environmental costs of energy production and use in consumer prices, led to higher levels of energy consumption in all industrial countries than would have occurred otherwise.

It is very difficult to quantify the environmental costs of energy use because many of these costs, such as the loss of wildlife habitat, are difficult to estimate in economic terms. In other cases, the impacts themselves, such as climatic change, are not well understood. Because they are not being borne by today's energy consumers, these costs are being passed on to future generations in the form of a degraded environment.

In order to correct the inability of the free market to measure and incorporate environmental costs, governments at all levels have intervened extensively to regulate the energy industries and influence consumer decisions. Attempts to take environmental implications into account in energy policy-making have so far concentrated on the "upstream" or supply side of this continuum. The techniques used to integrate environmental factors into the design of energy supply projects have relied extensively on the use of environmental impact assessments (EIAs). Project EIAs are now widely used in Canada and other industrialized countries and have proved successful at reducing the environmental costs associated with large-scale energy projects. Environmental assessments are also starting to be conducted on cumulative effects (e.g., uranium mining in Saskatchewan, hydroelectric development of the Moose River in Ontario).

In addition, agencies such as the National Energy Board, the AECB, the Alberta Energy Resources Conservation Board, and various government departments have imposed terms and conditions on projects and established standards for matters such as land disturbance and reclamation, allowable air and water emissions, and public safety, consultation, and compensation.

Demand-side management

To complement the environmental regulation of specific energy projects, policy-makers are increasingly shifting their attention towards the demand side of the energy equation. This shift has come about for several reasons. First and foremost is that the environmental costs associated with an energy supply project tend to be local or at most regional in nature; exceptions to this situation would be a large accident at a nuclear power plant whose effect could be felt internationally. Second, the most important environmental issues associated with energy are increasingly understood to be related to its consumption rather than to its production; they are therefore better addressed on the demand side than on the supply side. Reducing demand is one of the most cost-effective ways to alleviate environmental impacts at the production end of the fuel chain. Finally, the cost of remedial action is becoming prohibitively expensive. A preventive approach seeks to avoid environmental impacts by increasing the efficiency of energy use.

Over the last 15 years, the federal, provincial, and territorial governments have encouraged energy conservation through a variety of programs, including improved insulation standards for new building construction and subsidies to upgrade insulation in older buildings (e.g., the Canadian Home Insulation Program); introduction of more efficient furnaces; efficiency standards for automobiles; improved utilization of industrial waste heat; technology transfer and demonstration programs (e.g., the R-2000 energy-efficient house); and appliance labelling. Electrical utilities in several provinces are also starting to promote greater efficiency in the use of electricity by offering rebates for the installation of efficient lighting, encouragement to customers to shift loads to off-peak periods, information programs to their customers, and energy audits.

These efforts, combined with the impact of higher prices and increased consumer awareness, have tempered the growth in energy demand. Between 1973 and 1987, the total amount of secondary energy used per dollar of GDP fell by 30% (Marbek Resource Consultants 1989) as the result of both increased efficiency in energy use and structural changes to the economy (primarily changes in the industrial mix). This drop hides significant differences among sectors. During this period:

- the average household energy use declined by about 32%;
- the efficiency of Canada's automobile fleet increased by a third;
- energy use per square metre of commercial floor space declined by almost 18%; and
- the industrial sector reduced its use of energy for each dollar of output produced by about 6%.

Table 12.6 places Canada's performance in an international context. Canada's energy intensity has declined appreciably since the early 1970s but not as much as that of most of its major trading partners. The domestic potential for further energy efficiency gains is believed to remain very large, although experts disagree about its precise scope. A recent study completed for the federal government estimates that the potential for further economically attractive efficiency gains based on existing technology is in the order of 30% (Peat Marwick Stevenson & Kellog *et al.* 1991). This study was based on purely economic factors and provides a starting point only for assessing the energy efficiency potential in Canada. The federal government has no formal estimate of the potential for energy savings at present. The potential gains can make a substantial contribution to reducing atmospheric emissions from energy use.

Demand-side management focuses on improving the ratio between the quantity of energy input and the useful work output. Although this approach has demonstrated that there remains a large untapped energy efficiency potential in Canada, it understates how much energy Canada could really save because it does not consider the qualitative differences among various energy sources.

The introduction of quality considerations allows the analysis of the theoretical minimal amount of energy required to perform a particular task and, therefore, the savings potential available in

TABLE 12.8

Comparison of energy intensity in G7 countries

Country	Energy requirements (tonnes of oil equivalent per capita)	% change, 1970–88
Canada	9.6	–20.5
USA	7.8	–27.4
W. Germany	4.5	–22.5
UK	3.7	–33.1
France	3.7	–16.3
Japan	3.3	–30.9
Italy	2.6	–23.1

Source: Organisation for Economic Co-operation and Development (1991).

matching energy source to the quality of energy needed to meet a specific task. Between 1970 and 1988, Canada's per capita reduction in energy use was 20.5%.

Renewable forms of energy

Another strategy aimed at reducing the environmental impact of energy use involves the increased use of renewable forms of energy. Renewable energy can be derived from natural resources related to the solar cycle that are either inexhaustible or replenishable. Renewable forms of energy, such as wind and solar energy, tend to be more diffuse by nature than nonrenewable sources. They tap energy flows that are generally physical rather than chemical in nature (e.g., solar radiation, wind, flowing water) and therefore tend to impose physical rather than chemical impacts on the environment (e.g., noise, visual intrusion, disruption of rivers). These characteristics make renewable forms of energy generally more environmentally benign than nonrenewable forms. Exceptions would be large-scale hydroelectric development and biomass plantations for the production of liquid fuels.

As a result of its geographical diversity, Canada has a very large renewable energy potential, although significant barriers to its realization exist. These include high capital costs, lack of customer awareness, poorly developed infrastructure, and an energy pricing regime that does not recognize the environmental benefits of renewable forms of energy. Even so, renewable forms of energy are becoming economically attractive in selected applications (e.g., residential heating) and remote locations. Table 12.7 identifies the principal sources of alternative or renewable energy available, with the exception of the large-scale hydroelectric utility developments. As a result of a government-led effort in research and development since the mid-1970s, an industrial capability and embryonic service infrastructure now exists for a broad array of renewable energy technologies. However, federal support of renewable energy development through research and projects has declined since 1984 (Energy, Mines and Resources Canada 1991*a*).

Renewable energy meets 19% of Canadian primary energy demand, two-thirds of it in the form of centrally planned hydroelectric capacity. The other third, (approximately 7%) is primarily wood used for combustion in the forest industry (5%) and, to a lesser extent, in the residential sector (Energy, Mines and Resources Canada 1991*a*).

Based on a normal marketplace pricing, the National Energy Board (1991*b*) expects very little change in the share of primary energy demand in the next decade by alternative forms of energy. Except for the use of wood in the residential sector and wood waste in industry, existing technology for most alternative energy is still expensive, compared with that of conventional energy, when priced on a market basis. Changes in factors such as pricing mechanisms, tax policies, individual preferences, and technological breakthroughs could increase the share of alternative sources.

CONCLUSIONS

The large-scale use of energy leads to pervasive environmental impacts. These include: global atmospheric change; the restructuring of ecosystems from damming and diverting rivers for hydroelectricity generation; the accumulation of radioactive wastes; urban air pollution; the acidification of the environment; the alienation of land for production and transportation facilities; and water pollution as a result of leaching, spills, and the long-range transport of air pollutants. Some of the environmental stresses associated with energy use take years to become apparent. The resulting uncertainty over the extent of the stress and its timing makes it difficult to design appropriate remediation strategies in these cases. Perhaps the best example of this uncertainty is the likely scale and impact of global warming on Canada.

A different kind of uncertainty emerges in attempts to trade off the environmental impacts of various energy sources. Because these impacts vary so much in nature, time, and space, they are not directly comparable. A case in point is the environmental risk associated with global warming and high-level radioactive wastes. Although nuclear energy and fossil fuels can be substituted for each other in generating electricity, it is very difficult to conclude whether such substitution would do more than trade one environmental risk for another. This is one of the reasons why the most effective way of achieving environmental goals lies in reducing energy demand rather than mitigating the adverse effects of new supplies.

Table [illegible]

Principal sources of alternative renewable energy

Source	Description
Small low-head hydro	Run-of-the-river devices, small hydraulic turbines (under 15 MW), tidal power: half of the 400 hydroelectric stations in Canada are small hydrostations and generate only 10 MW of the more than 60 000 MW of hydroelectric generating capacity in Canada
Active solar	Direct conversion of solar radiation into thermal energy; their greatest potential is in remote locations
Passive solar	Collection, control, storage, and distribution of solar energy through building design; estimates indicate that as much as 363 PJ per year could be saved by the year 2010
Photovoltaics	Direct conversion of light into electricity
Bioenergy	The collection of biomass residues and the harvesting of woody biomass for conversion into an energy form
Wind energy	The conversion of kinetic air energy into mechanical and/or electrical energy; shows great potential for remote communities
Geothermal energy	The use of the heat in the Earth's crust; very little active development in Canada

Source: Energy, Mines and Resources Canada (1991*a*).

Several environmentally significant energy trends have become evident in the past few years. These trends are expected to continue in the foreseeable future:

1. *Increased efficiency in energy use*

   Although the rate of efficiency improvement has dropped primarily as a result of the collapse in world oil prices in the mid-1980s combined with less public concern and attention, significant gains have been made since 1973, and further improvements can be made. As noted above, energy conservation is the most effective approach that can be taken to reduce the environmental impacts of energy use over the long term.

   Demand-side management of the energy sector will play a major role in the next round of efficiency and conservation strategies, particularly electrical generating utilities. Utilities and other energy sectors will not get more use of existing efficient technologies without a significant change in behaviour and attitudes towards the conservation of energy.

2. *Greater energy intensity of supply systems*

   It takes more and more primary energy to produce the same amount of secondary energy. Conversion losses from primary demand to total end-use demand between 1969 and 1989 increased from 12 to 20%. There are two main reasons why conversion losses have been increasing, in spite of technological improvements. The most important is that Canada's reliance on less efficient coal- and nuclear-based electricity is increasing. The second is that the most accessible and cheapest energy sources are typically exploited first. As these run out, more distant and more expensive sources are developed. These sources often require a greater energy input in their production process. The production of heavy oil or bitumen from the tar sands, for example, is more energy-intensive than the production of conventional oil reserves. In a related vein, the more distant an energy source from market, the more energy will be used to transport it to consumers. Electricity transmission losses, for example, increase with distance. As hydroelectric dams are built in increasingly remote locations, an increasing share of their production is used purely to deliver their output to market (7% of the power produced at James Bay and Churchill Falls is used in transmission).

3. *Shift in the mix of energy sources*

   There has been a real shift from oil in favour of natural gas and electricity. The easier aspects of successfully shifting to electricity have been achieved. There is no single source to meet future demand. The real question is, "what will be the mix of fuel sources in each region of Canada that can minimize the full range of potential environmental impacts?"

   Oil use is increasingly limited to the transportation sector where few economic alternatives exist. If the environmental concerns over emissions and related impacts from the transportation sector are to be reduced, profound changes in the consumption of energy in this sector will have to be addressed.

   Oil, however, will continue to play an extremely important role in determining the environmental impacts of energy use. Because it is the most widely traded energy commodity, oil influences all energy prices. The world oil price will remain, for the foreseeable future, the single most important factor influencing the economics not only of oil supply projects, but of renewable sources of energy and the penetration of efficiency technologies as well.

4. *Reduced air emissions*

Through regulatory action and international negotiations, Canada has achieved major reductions in the emissions of gases contributing to acid rain. In time, these reductions should lead to the recovery of some of the affected areas. As a result of more complete combustion and catalytic converters, as well as gains in automobile fleet efficiency, both largely prompted by regulatory action, Canada has also realized important improvements in urban air quality. Further improvements in new car emissions may take place if Canada moves towards the tougher California standards in the near future. Increases in car ownership and use, however, are offsetting in part the gains made in individual car emissions.

Options for controlling CO_2 emissions are more limited, as no satisfactory technological solution exists to remove CO_2. The target to which Canada has committed itself, of capping emissions of CO_2 and other greenhouse gases at 1990 levels by the year 2000, is a first step. Further reductions are required and should be based on a program of targets and schedules agreed to internationally. The cost of a 60–70% cut in global CO_2 emissions, however, which many scientists believe would be necessary to stabilize CO_2 concentrations in the atmosphere, would be substantial and would likely amount to billions of dollars annually. It would entail a massive switch to non-fossil fuel energy sources with very profound implications for industrial societies.

5. *Increased impacts from electricity*

Although Canada has been successful in reducing the environmental impacts associated with the use of fossil fuels, it has done so in part at the expense of greater environmental restructuring from hydroelectricity production and the risks associated with a higher reliance on nuclear energy. The continued high growth in electricity demand and the increasing scale of hydroelectric development imply that the use of electricity will impose mounting environmental costs in the future.

The greatest challenge in the energy sector today in Canada and other industrial countries, where the bulk of the world's fossil fuels are consumed, is what to do about climatic change. More specifically, it is how to bridge the gap between what some believe is possible and what some claim is necessary. On the one hand, some argue that absolute reductions in CO_2 emissions of even a few percent would require a substantial effort, involving a major commitment to increased efficiency, fuel switching, and substitution in transportation modes (Robbert Associates and Robinson 1989). On the other hand, climatologists are increasingly agreed that a 60% reduction in CO_2 emissions will be required to stabilize atmospheric concentrations at 1990 levels and avoid major changes to the world's climate (Intergovernmental Panel on Climate Change 1990).

Humanity is thus caught on the horns of a dilemma: make the significant lifestyle changes implied in reducing fossil fuel use in order to slow down the rate of climate warming; or maintain current lifestyles and be forced to adapt to the economic and environmental consequences of a warmer climate. This is one of the most difficult dilemmas of our time because it challenges the very basis of our prosperity: the use of cheap fossil fuels. Among other things, the availability of these fuels has spurred economic growth, enormously enhanced individual travel, transformed urban design, created new industries, and changed agricultural practices. The influence of fossil fuels on modern industrial society is so pervasive that it makes it difficult even to conceive what a post-fossil fuel future would look like.

Canadian energy policy has traditionally focused on ensuring security of supply to Canadian energy consumers and on the development of Canada's energy supply industries as elements of broader national and regional economic development objectives. As evidence continues to mount that present patterns of energy consumption are environmentally unsustainable, future energy directions must begin to address more difficult trade-offs, including the impacts of current energy choices on future generations. As yet, all nations still do not have a solution to reconciling the burgeoning demand for energy with the need to maintain a viable global ecosystem.

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COURTESY OF INDUSTRY, SCIENCE AND TECHNOLOGY CANADA, OTTAWA

HIGHLIGHTS

In 1986, more than three-quarters of the Canadian population lived in urban areas, half of them in the Quebec City to Windsor corridor.

■

Ozone, the main contributor to photochemical smog, is perhaps the most serious of the urban air pollutants.

■

At 360 L daily, Canadian per capita water consumption is the second highest in the world.

■

Municipal sewage is a principal source of water pollution, chiefly because much of it is untreated or inadequately treated. In 1989, 30% of Canada's population had no sewage treatment of any kind.

■

Canadians are the heaviest energy consumers in the world, each using the equivalent of 8 800 kg of oil in 1983. Measures taken by government to reduce energy consumption have met with some success.

■

Canadians are the world's leading producers of waste and most urban areas are running out of space for sanitary landfills.

■

The complex dynamics of changes in urban structure, including changes in population size, average population densities, and city shape, make it exceedingly difficult to tally the environmental impacts of today's cities.

■

In the 20 years of urban growth from 1966 to 1986, large Canadian cities spread chiefly onto agricultural land; of the 301 440 ha of rural land urbanized, 58% was of high agricultural capability.

■

The single-family house and the private car contribute heavily to energy consumption in Canada. More than 50% of all dwellings constructed in Canada in 1990 were single-family homes, and 77% of all households owned one or more cars in 1977.

■

Urbanization in itself is not the environmental evil it is widely assumed to be. Instead, it is people and their activities that pollute air and water, use energy and materials, and create waste.

■

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> “A city in harmony with nature is still a futuristic vision, but it is not a pipe dream. Everything necessary to create these cities of the future is now within our capabilities.”

INTRODUCTION

The entire evolution of human settlement is represented in contemporary Canada, from unpopulated wilderness, through hunting and gathering without permanent occupancy, to extensive agriculture, small permanent settlements, larger and more complex towns, and, ultimately, cities and metropolitan regions housing millions of people.

At each stage of this continuum, human impacts on the natural environment become more evident. Less than 0.2% of Canada's land area is urban — only 15 700 km² out of nearly 10 million (Welch 1980) (Fig. 13.1) — yet the environmental implications of the human activities concentrated in and around those small tracts vastly outweigh those in all the rest of the country.

In the large city, in particular, with its enormous concentration of people, the demands and stresses that humans place on the environment are focused on a limited space. Cities destroy or greatly alter the natural ecosystems in which they were built. Urban growth results in the loss of natural resource capabilities and environmentally significant features. City populations consume vast quantities of energy and create air and water pollution; city infrastructures, such as transportation systems, can exacerbate these environmental effects. The impacts extend well beyond the urban area proper through a diversity of urban-related operations and land uses, from resource extraction and the production of pollutants to the creation of built environments in the hinterland. However, it is important to distinguish between the environmental impacts of urbanization, as such, and the impacts of people and their activities. Few of these impacts would be less, and some would be greater, if city populations were dispersed rather than concentrated in urban areas.

In this chapter, the environmental implications of human activities in Canadian urban centres are explored, with some discussion of actions that are being taken to minimize the impacts.

CANADA: AN URBAN COUNTRY

The state of Canada's environment, including natural environments in and around cities, is increasingly influenced by urban places[1] and their people, but the relationship is extremely complex and not susceptible to sweeping generalizations. It is, nonetheless, a very important aspect of Canada's environmental health, because Canada — despite its vast tracts of almost unpeopled land and its very low overall population density — is an urban country. Although over three-quarters of Canada's population was rural in 1871 (Fig. 13.2), by 1986 more than three-quarters — 19.4 million out of 25.3 million people — lived in urban places (Mitchell 1989). Among 146 countries studied by the World Resources Institute (1990), Canada is the 28th most urbanized (Fig. 13.3).

All but a handful of Canada's urban places are in a relatively narrow belt immediately north of the United States. In 1986, almost three-quarters of Canadians lived within a two-hour drive of the U.S. border (Mitchell 1989). The level of urbanization varies substantially: it approaches 80% in British Columbia, Alberta, Ontario, and Quebec but is approximately 50% in most of the other provinces. Prince Edward Island is the only jurisdiction whose population is still predominantly rural.

Contemporary Canada has two overlaid but distinct urban systems. One of these extends across the country in the form of a roughly linear series of cities spaced widely apart. Each city has its own economic base and functions as the principal service centre for a large region. Toronto is the centre of this nationwide

---

[1] An urban place, as defined by Statistics Canada, has a population of at least 1 000 concentrated within a continuously built-up area, at a density of at least 400 per square kilometre. In this chapter, "city" means a large urban place with a population of 100 000 or more, and "town" means any smaller urban place. "Urban area" and "urban place" are all-inclusive terms used interchangeably. All these terms, and proper names, denote the entire urban area regardless of municipal boundaries.

FIGURE 13.1

Urban settlements in Canada

The population distribution in Canada by census division for 1986 is shown. Each dot represents 1 000 persons.

Source: Statistics Canada, Geography Division.

system, as measured by such criteria as financial functions, information flows, air traffic, and the provision of various specialized services. Montreal, too, plays a major role, and Vancouver's importance is growing as Canada's relations with the Pacific Rim intensify.

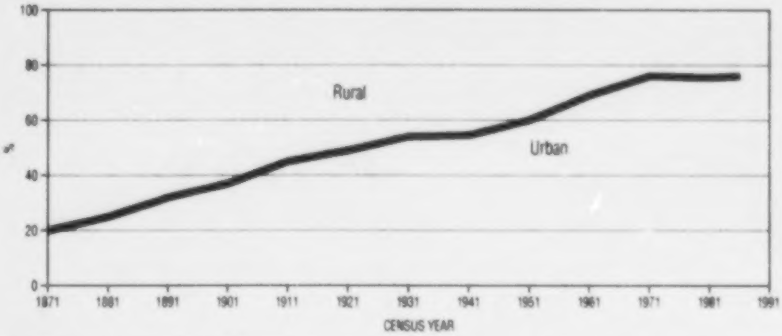
The second system is the 1 000-km Quebec City to Windsor corridor, which has been termed "Canada's Main Street" (Gertler *et al.* 1977; Bond 1986). This relatively densely settled segment of the nationwide system embraces a network of urban areas, including 9 of the country's largest 15 cities (Yeates 1975, 1985). Many of these cities are tightly linked both functionally and physically. The urban belt along the north shore of Lake Ontario is now almost continuous from Oshawa through Toronto to Hamilton, and all of south-central Ontario, including St. Catharines–Niagara Falls and Kitchener–Waterloo–Guelph, increasingly has to be regarded as a single functional urban complex (Metropolitan Toronto and Region Transportation Study 1966; Government of Ontario 1970; Central Ontario Lakeshore Urban Complex Task Force 1974).

Not all Canadian settlements are located within these systems; many are scattered across the midnorthern resource frontier, within major agricultural areas, and along all three ocean coastlines. Most of these are too small to be classed as urban, such as Newfoundland's outports, British Columbia's coastal logging communities, Manitoba's farm hamlets, and hundreds of aboriginal settlements. Some mining towns, however, are substantial: Sudbury, for example, has a population of nearly 150 000. Virtually all these settlements depend heavily on the exploitation of natural resources either for the market or for subsistence. Their relationship with the natural environment is immediate and fundamental.

Although many of these resource-based settlements continue to survive, it is a precarious existence. In recent decades, the economic base of Canada and the urbanized western world has fundamentally shifted from the traditional heavy manufacturing and resource-based "smokestack" industries to information-based service and high-technology industries. The importance of this shift from an environmental standpoint is self-evident, although, to some extent, it represents a transfer of the industrial environmental burden to parts of the world less able to deal with it. Even for Canada, the shift is not a pure environmental gain: it has been accompanied by a considerable growth in road freight movement, for instance.

FIGURE 13.2

Urban–rural population change in Canada, 1871–1986



Source: Mitchell (1989).

Canada's economic transformation has greatly affected the distribution of urban growth. Whereas it was the discovery of oil that propelled Edmonton and Calgary from modest regional centres in 1951 to Canada's fifth and sixth largest cities, respectively, other cities that have moved up in national size-ranking, such as Saskatoon and the Ontario cities of Toronto, Ottawa, London, and Kitchener–Waterloo, reflect the growth of the information-based economy. Cities whose economic base is in primary or heavy manufacturing industries, such as Winnipeg, Saint John, and the Ontario cities of Windsor, Hamilton, Thunder Bay, and Sudbury, have lost ground. Sudbury's population actually declined after 1971 as employment in the nickel industry fell sharply (Robinson 1981; Hooper *et al.* 1983; Simmons and Bourne 1984, 1989).

CITIES AND THEIR NATURAL ENVIRONMENTS

Cities cannot exist in isolation from nature. Indeed, every Canadian city owes its birth to a natural harbour, the form of a river system, the qualities of the soil, the presence of an ore in the bedrock, or some other natural phenomenon. As cities grow, their patterns are largely determined by landforms and the characteristics of the landscape.

The urban environment may appear a wholly human artifact almost entirely cut off from nature, but this is not the case. Winnipeg urbanites, for example, still struggle through winter winds along Portage Avenue; Montrealers find relief from the heat of summer under the trees of Mount Royal. More fundamentally, city people need air to breathe, water to drink, resource-derived energy and materials for almost all their activities.

Canadians tend to distinguish sharply between "city" and "country" as totally different and almost unrelated environments. Yet in *The granite garden*, author Anne Spirn writes, "Nature is a continuum, with wilderness at one pole and the city at the other. The same natural processes operate in the wilderness and in the city" (Spirn 1984). Even standing in the heart of a large city, surrounded by tall office buildings, we see the sky, feel the wind and rain, and are likely to see somewhere an uncultivated spot of green cautiously emerging through a crack in the ubiquitous pavement. As we move away from the city centre, we probably soon encounter a lake or a river, the sea, or stretches of field and woodland. We find no clear-cut boundary separating the city from its rural surroundings, but a gradual, untidy transition from one to the other.

Green space in the city

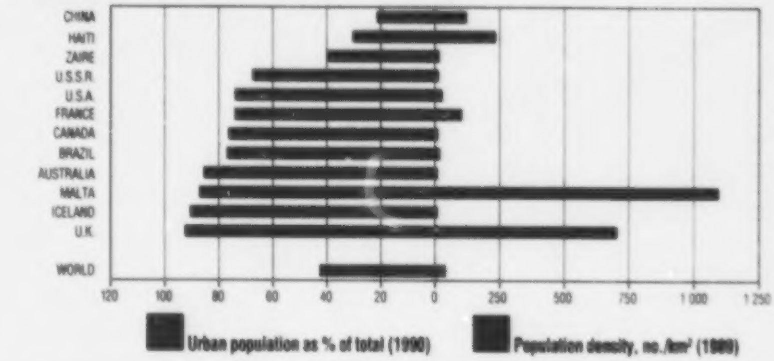
In the urban environment, nature is most tangible in the surviving green spaces both in and around the city: woodlots, wetlands, river valleys and ravines, uncultivated grasslands, hedgerows. Some of these places have been deliberately maintained and protected; some have simply been bypassed by urban growth; others are abandoned sites that nature has reclaimed. Despite their often limited extent and random occurrence, these remnants can serve many important functions: prevention of soil erosion; flood control; enhancement of air and water quality; microclimatic and noise regulation. Some very important areas maintain biotic diversity and preserve natural ecosystems, including unique ecological features such as the Carolinian forest remnant in Toronto's Rouge River valley, the subarctic peat bog at Mer Bleue on the edge of Ottawa, and the tall-grass prairie near Winnipeg. As well as their ecological value, these areas may well be visually appealing and offer urbanites the opportunity to hike and view wildlife.

Within the city proper, natural areas are generally formally designated urban parks, which vary greatly in size, physical character, and use. Some very large tracts — Vancouver's Stanley Park, for example — still include something resembling the original wilderness. Other relatively small parks, such as Montreal's Phillips Square, are entirely urban, intensively used spaces. Between these two extremes is a range of park types: fields for games and sports, children's playgrounds, ornamental gardens, small neighbourhood parkettes for "sitting out." These open spaces vary considerably in environmental value.

Although a few urban parks are large enough to support natural ecosystems and provide habitat for a range of wildlife, even these are substantially affected by their urban surroundings. Much of Montreal's Mount Royal is dedicated to cemeteries, and most is a carefully planned urban park rather than a wilderness area. (Nevertheless, a municipal proposal that would have increased accessibility and intensive recreational use of the park was recently rejected by the public in favour of retaining Mount Royal's qualities as a

FIGURE 13.3

Canada in an urbanized world: population density and urban population for selected countries



Note: Out of 146 countries, Canada has the eighth lowest population density and is the 28th most urbanized.
Source: World Resources Institute (1990).

nature preserve.) Most of the ravines that once dissected the Toronto area have been lost or heavily degraded as a result of filling, dumping of garbage, channelization and diversion of watercourses, and construction of roads and rail lines. A substantial portion even of Stanley Park is given over to intensive recreational uses. The areas that remain are frequently so intensively used by walkers, joggers, cyclists, and skiers as to lose much of their biotic and ecological character.

Most other urban parks are given over to recreation. Active sites, such as football fields, baseball diamonds, skating rinks, and playgrounds, offer no significant environmental values except to the extent that they reduce surface runoff and perhaps include a small landscaped area or a few trees. They may well have a negative environmental influence — in energy consumption for facility maintenance and ice making, for example. This is true even of golf courses: although they frequently include substantial treed areas, they are dependent on energy- and water-intensive irrigation systems and are extensively treated with herbicides and fertilizers.

The recreation parks that are managed primarily for intensive if relaxed use, and for visual appeal, include ornamental botanical gardens and expanses of well-mown grass dotted with trees. The introduction of nonindigenous plant species is often disruptive to the natural ecosystem, displacing native species or introducing new diseases. The manicured park, although important in meeting the recreational needs of an urban population, can reduce biodiversity. And, like golf courses, these areas are usually heavily treated with pesticides, herbicides, and fertilizers that contribute to the pollution and eutrophication of rivers and lakes. Fortunately, some cities are attempting to reduce reliance on chemicals by employing integrated pest management programs.

Much of the city's green space is privately cared for: the yards of urban dwellings and allotment gardens, for example. Apart from their value to individual households, these areas collectively contribute to the attractiveness of the city. Together with city tree-planting programs, they also improve local air quality, reduce runoff, and help to reduce waste through composting; again, the widespread use of pesticides and chemical fertilizers somewhat offsets these environmental gains.

Although these green spaces are often surrounded by busy urban environments that are not hospitable to wildlife, many species have adapted. Raccoons, woodchucks, foxes, badgers, and skunks use garages, garbage landfills, and culverts as den sites. Landfills also supply food for bears, gulls, and crows, as well as rats, mice, some snakes, and earthworms (Leedy *et al.* 1978). The creation of new waterfront land by filling, as in the case of Toronto's Leslie Street Spit, can provide fish, bird, and even animal habitat, although filling can also destroy fish habitat and disrupt aquatic ecosystems.

The greening of the city

Across Canada, cities are attempting to enhance both the environmental and the recreational value of urban park systems and to promote a greener and biologically richer urban environment.

- Some cities are trying to preserve and even extend natural corridors, such as Edmonton's Whitemud Ravine, which provides a home for deer, coyotes, beaver, rabbits, and other small mammals, as well as birds, reptiles, and insects.
- Cities are creating new areas for nature, sometimes almost by accident. Toronto's Leslie Street Spit, built by lakefill, was originally intended to expand port facilities but has become a major natural area inhabited by over 300 bird species, 275 botanical species, and several amphibian, reptile, and mammal species (Friends of the Spit 1990*a*, 1990*b*). It is now officially a park.
- Montreal is developing a linked open space network by creating green corridors connecting existing parks, the grounds of religious institutions, old industrial sites, shorelines, and other green or potentially green spaces. The network will be suitable for walking and cycling and will also help to restore biological diversity and reestablish ecosystems.
- Montreal, Toronto, Winnipeg, Vancouver, Halifax, and other cities with waterfronts are reclaiming them from obsolescent industrial or port uses and reserving at least some areas as open space. Cities with

FIGURE 13.4

Major air pollutants for selected Canadian cities[a]

City	Sulphur dioxide (ppb)	Nitrogen dioxide (ppb)	Ozone (ppb, 1 hour)	Carbon monoxide (ppm, 8 hour)	Total suspended particulates (µg/m³)
Maximum acceptable concentration	23	53	82	13	70
Maximum desirable concentration	11	23	50	5	60
Toronto	5.1	26	100	3	65
Montreal	7.1	27	85	3	40
Vancouver	6	25	58	4.8	36
Ottawa	4.5	28	45	2.5	43
Edmonton	3	24	60	3.6	46
Calgary	3	28	55	4.0	54
Winnipeg	1.5	17	80	2	46
Quebec City	5	31	70	3	*
Hamilton	12	25	110	2	83
St. Catharines–Niagara Falls	6	21	60	2	55
London	6	22	100	2	57
Kitchener	3	25	80	3	60
Halifax	11	12	65	2	35
Victoria	nm	nm	nm	nm	33
Windsor	8	28	100	2	54
Oshawa	6	24	110	3	55
Saskatoon	0.0	15	60	1	31
Regina	*	14	60	3	39
St. John's, Nfld.	8	nm	90	3	31
Chicoutimi–Jonquière	nm	nm	nm	nm	nm
Sudbury	8	11	80	1	36
Sherbrooke	nm	nm	nm	nm	46
Trois-Rivières	8	nm	nm	nm	46
Kingston	nm	nm	nm	nm	
Thunder Bay	0.0	12	70	2	37
Saint John, N.B.	10	*	70	2	32
Sydney, N.S.	2	nm	nm	nm	41
Fredericton	nm	nm	nm	nm	30
Charlottetown	2	nm	nm	nm	22
Whitehorse	nm	nm	nm	nm	32
Yellowknife	nm	nm	nm	nm	63
Dorset	2	19	138*M		19

* insufficient data collected

nm not measured

*M based on absolute maximum ozone peak (other measurements use 99.9 percentile, but this was not available for Dorset)

[a] Based on city average.

Source: T. Furmanczyk, Environment Canada, Regulatory Affairs and Program Integration Branch, personal communication.

rivers and creeks are trying to restore their waters and shores to their original quality.

- Municipalities such as North York, Ontario, are beginning to naturalize parts of their park systems by encouraging them to return to an approximation of their original natural state.

- Several cities and private agencies are promoting extensive tree planting: every city has unused land on roadside verges, boulevards, and around public buildings on which trees can be planted. Quebec City has initiated an urban forestry program, including technical guides, tree protection regulations, a computerized inventory of trees, and management programs. Halifax's newly amended Municipal Development Plan calls for shade tree protection and planting programs.

- Peregrine Falcons, an endangered species, have been successfully established in city centres. In Montreal, they nest on the Sun Life Building on Dorchester Square and prey on pigeons.

- In some cities, such as Vancouver and North York, experiments are under way to replace lawn maintenance machinery with sheep or geese, although this may create a perceived nuisance problem for the public.

This greening reflects the city dwellers' growing awareness of the importance of nature and green space to both the environmental and social health of the city and the physical and mental health of its people. Such awareness is fostered by the influence of such movements as Healthy Communities/Villes en santé, which brings many sectors and interest groups together to develop projects to improve the quality of life in the community (Canadian Institute of Planners 1989). To reintegrate the natural and built environments, however, a great deal of long-term effort is still required.

TRANSFORMING THE URBAN ENVIRONMENT

Green space is a clearly visible link between the built and natural environments, but even more fundamental links tie the city to the total ecosystem. The very existence of city people depends on air, water, energy, materials, and land. Each is indispensable to the city; each is used and reexported in altered and even completely different forms as the city channels and modifies the complex flows of the natural ecosystem.

Transforming the air

It is the activities of city inhabitants, rather than the city itself, that depend on air and change its characteristics. Nevertheless, the concentration of people and activities in the city and, to some extent, the built environment itself do have particular consequences for the atmosphere.

City air is usually more polluted than the air of the surrounding countryside, and certainly more so than the air of remote regions. The city not only produces more pollutants but also can create microclimates, such as urban heat islands, which are caused when the hard surfaces of city streets and structures absorb and then reradiate thermal energy. The city's atmosphere exacerbates the heating: airborne contaminants typically found in higher concentrations in urban environments directly absorb solar energy and reradiate heat. The warming is further supplemented by the heat from vehicles and buildings. The temperature of a Canadian city can rise by an average of 1–2°C, and by as much as 12°C in extreme cases. (For a more complete treatment of the causes and effects of urban heat islands, see Chapter 2.)

Curbing urban air pollution

The chief air pollutants in Canada are sulphur dioxide, nitrogen dioxide, ozone, carbon monoxide, and suspended particulate matter, which includes both particulates from natural sources, such as dust from forest fire ash, and human-produced particulates, such as incompletely combusted hydrocarbon fuels. As the principal sources of these well-known air pollutants are vehicles, residential heating, and commercial and industrial processes, they are heavily concentrated in cities and towns. Figure 13.4 shows recent levels of these pollutants in Canadian cities.

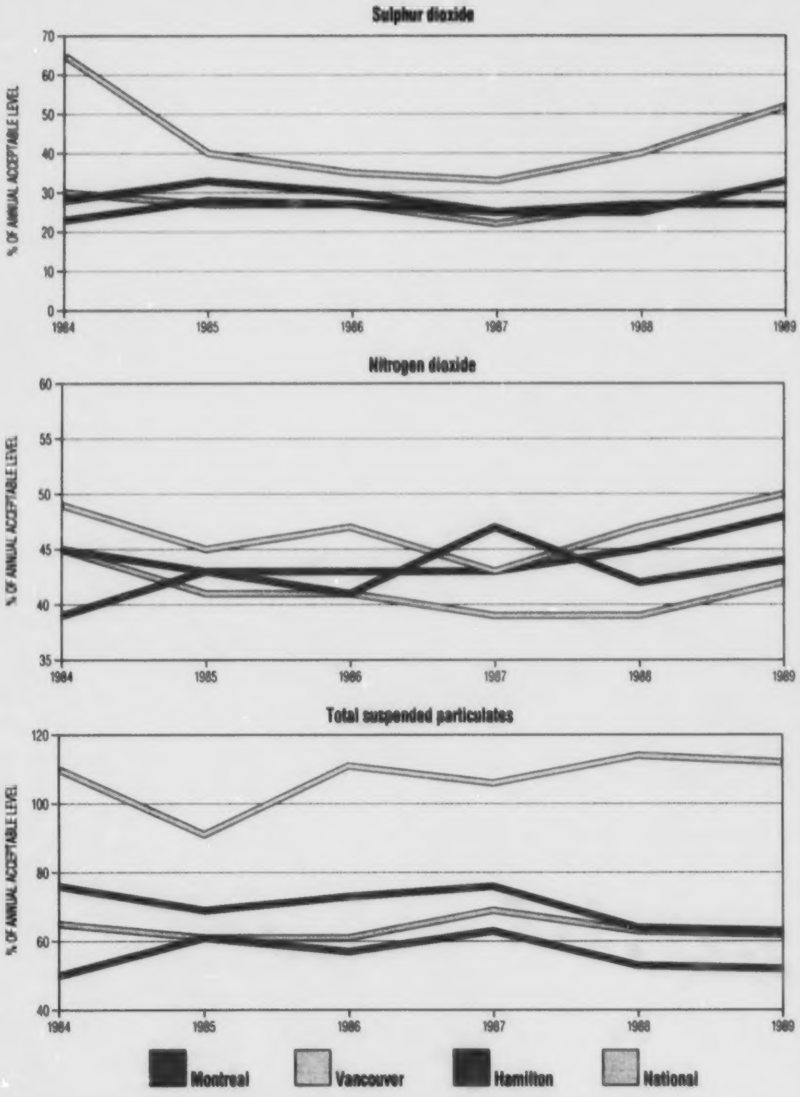
The levels of these pollutants are measured by a national system of air pollution monitoring stations known as the National Air Pollution Surveillance (NAPS) network. These stations are located in urban areas in order to monitor air quality where a great number of people can be affected. The monitoring makes it possible to respond quickly to high urban pollution levels. However, each station can measure air quality only in its vicinity, which may not be representative of a wider area, and there is no comprehensive rural monitoring network. Comparisons of urban and rural air quality are therefore limited to one or two pollutants in a few areas. (For further information on NAPS, see Chapter 2. For a broader discussion of pollutants, see Chapters 2 and 21.)

All levels of government have acted to reduce air pollution. The federal government, for example, has legislated the phasing out of leaded gasoline, and some provincial governments have imposed increasingly stringent controls on industrial atmospheric emissions. Some provincial and municipal governments have taken steps to discourage the use of private cars in urban areas and encourage the use of mass transit and bicycles. The federal and provincial governments have also jointly established a set of national air quality objectives.

These measures have achieved some success. Between 1977 and 1989, for example, the mean level of sulphur dioxide monitored by NAPS declined by 52%, of nitrogen dioxide by 32%, of carbon monoxide by 63%, of airborne lead by 93%, and of total suspended particulates by 44%. Although both natural and industrial sources of airborne particulates are to a considerable

FIGURE 13.5

Trends in air pollutant concentrations for Montreal, Vancouver, and Hamilton, 1984–89



Source: Environment Canada (1989).

extent located outside urban areas, the drop in urban particulate levels illustrates the beneficial effects of using cleaner energy sources, such as natural gas, of technical innovations such as more efficient furnaces, and of other cleaner industrial and commercial processes. Particulates have also been reduced through cities' replacement of loose sand and gravel surfaces with grass and asphalt (Hilborn and Still 1990).

Although there is considerable variation among cities and among different areas in each city, Figure 13.4 shows that the national air quality objectives are now broadly met (Statistics Canada 1986; Furmanczyk 1987). One city that has made a dramatic recovery is Sudbury, whose nickel smelters had long been notorious as one of North America's worst sources of air pollution and a prime cause of acid rain. Twenty years ago, the emissions of sulphur dioxide and other pollutants blackened the buildings of the city, destroyed vegetation over a wide area around it, and created a choking smog in periods of atmospheric inversion. Since then, mean sulphur dioxide levels have been reduced by 83%. Sudbury industries closed old smelters and modernized others using new processes and pollution reduction technology. (The construction of a 381-m "superstack," however, was one measure that succeeded only in dispersing emissions at the expense of downwind areas.) The striking improvement in local air quality enabled the city to undertake a massive program of revegetation, as well as a major restructuring of the city's economy (Richardson *et al.* 1989).

Continuing air quality problems

Although levels of key pollutants have generally decreased nationwide, city air quality problems are far from solved. Over the past few years, the downward trend of some pollutant levels seems to have stalled (Fig. 13.5). Levels are still high enough to create secondary pollutants, such as ozone, which are serious local problems.

Acid rain still poses a major threat, both nationally and internationally. Although the smelting industry in Sudbury, and indeed Canadian industry as a whole, has worked to curb the air pollutants involved, acid rain remains a major scourge of areas far removed from the source of the pollution (see Chapter 24). In some cities, trees and other vegetation are suffering, as are many city buildings.

While not noxious, carbon dioxide emissions are another form of air pollution that upsets the balance of gases in the global atmosphere. The effects of carbon dioxide on the environment are far less visible than those of other air pollutants, but are potentially exceedingly dangerous. Carbon dioxide is a prime contributor to the greenhouse effect, yet levels worldwide continue to rise (see Chapter 22).

One of the primary villains responsible for increasing carbon dioxide levels and other environmental pollutants is the automobile. Globally, the use and production of automotive fuel account for an estimated 17% of all carbon dioxide produced by the use of fossil fuels (Reener 1988); within Metropolitan Toronto alone, automotive fuels contribute 10 million tonnes of carbon dioxide to the atmosphere annually, and the figure is projected to increase by 25% over the next 15 years (City of Toronto 1989).

Automobiles and other vehicles are also the chief source of carbon monoxide and atmospheric hydrocarbons and an important source of nitrogen oxides. Indirectly, vehicles are a major cause of ground-level ozone as well (Canadian Urban Transit Association 1990).

Ozone: a common cause of poor urban air

Ozone, which constitutes approximately 90% of photochemical smog, is perhaps the most serious of the urban air pollutants; Ontario's air quality index reports ground-level ozone as the most frequent cause of poor air quality in urban areas.

Ground-level ozone is produced during the warm months, when sunlight enables complex reactions between nitrogen oxides (NO_x) and volatile organic compounds (VOCs), primarily hydrocarbons (see Chapter 2). Because vehicles, industries, and household solvents are primary sources, most ozone is urban in origin, but the pollution plumes that develop over heavily populated urban areas can be transported over long distances. Thus, photochemical smog can spread over wide areas. Extreme examples include the smog blankets that can cover large parts of southwestern California and the U.S. eastern seaboard during much of the summer.

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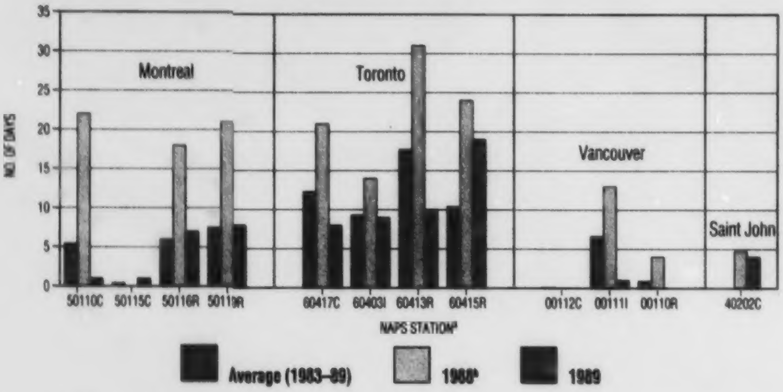
Days of unhealthy ozone levels

Number of days with ground-level ozone exceeding acceptable levels (>82 ppb).



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[a] Selected class 1 sites from four cities. Land-use types: R = residential, C = commercial, and I = industrial.

[b] 1988 has the highest numbers recorded thus far.

Source: National Air Pollution Surveillance (NAPS) network.

A typical ozone episode develops when there is a stagnant air mass over a heavily populated region during a succession of warm, sunny days; in Canada, therefore, high ozone levels usually occur between May and September. Locally generated ozone is frequently augmented from distant sources: the pattern of this long-range transport is determined by the prevailing winds. Sea breezes funnel emissions from the Greater Vancouver area eastward up the lower Fraser Valley, so that peak levels in the valley usually exceed those recorded in Vancouver. Similarly, prevailing southwest winds transport emissions from U.S. sources around the Great Lakes to the Quebec City to Windsor corridor, adding to the emissions produced within the corridor. Between Windsor and Toronto, peak ozone levels of 110–160 ppb are frequently recorded, with maximum levels approaching 190 ppb, compared with the maximum acceptable air quality objective of 82 ppb over a one-hour period (Ontario Ministry of the Environment 1988; Air Pollution Control Association 1989).

Ozone episodes therefore pose a health threat not only to urban residents but also to those who live downwind. Health problems, such as lung damage, are most likely to occur during short-term episodes of high ozone levels in the summer months. Ozone-caused crop damage, on the other hand, depends more on high average levels over the growing season (Hilborn and Still 1990). These average levels have shown little change since 1979, although 1988 levels were slightly elevated (see Chapter 2).

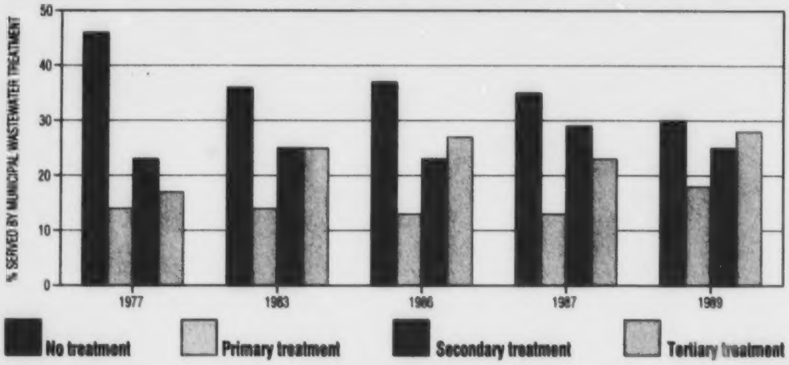
Short-term episodes have fluctuated widely between 1983 and 1989: Figure 13.6 shows the number of times that the air quality objective was exceeded in selected cities. Even at monitoring stations within the same city, the number of episodes varies considerably. Ottawa, for example, has one monitoring station downtown and another in a park near the Rideau River. Between 1983 and 1989, the park station recorded an average of 3.7 days per year in which the one-hour ozone reading exceeded the maximum acceptable level of 82 ppb, while the downtown station recorded none. Not only is the frequency of episodes highly variable; so are the ozone levels. At the Ottawa stations, ozone levels are consistently higher at the park site than in the busy city centre.

Although a variation in ozone levels is not surprising, the Ottawa findings

FIGURE 13.7

Wastewater treatment for Canadians

Primary treatment reduces the level of total suspended solids (TSS). Secondary treatment reduces biochemical oxygen demand (BOD) and additional TSS. Tertiary treatment reduces nutrient content and some persistent toxic chemicals.



Source: Environment Canada, Municipal water use database (MUD), National inventory of municipal waterworks and wastewater systems database (MUNDAT).

were interesting: ozone levels should seemingly be at their highest in a city centre where levels of source pollutants are also at their highest. This turnabout highlights the difficulty of dealing with ozone. The explanation probably lies in relatively high levels of nitric oxide at the downtown location. Nitric oxide reacts with ozone to form nitrogen dioxide; it is described as an ozone "scavenger." The downtown station is close to a busy commuter bus stop and regularly records maximum nitric oxide levels of 80 ppb over a 24-hour period, compared with 50 ppb at the other station.

The atmospheric chemistry and the meteorological factors that govern ozone levels are especially complex. Because ground-level ozone is a secondary or derived pollutant that cannot be controlled directly, it is necessary to control the substances from which it is derived: nitrogen oxides and VOCs. However, it is difficult to determine whether it is more effective to attempt to control nitrogen oxides alone, VOCs alone, or both together. Even difficult and expensive computer modelling and analysis are sometimes inconclusive. Given what is known, the solution now seems to be to attempt to reduce emissions of both. This makes motor vehicles and their use a prime target, as they are important sources of both nitrogen oxides and VOCs. The first phase of a national NO_x/VOCs Management Plan has targeted the reduction of emissions of these two groups of substances from all significant sources by about 700 000 t by the year 2005.

Transforming water

Water cycles continuously in the Ecosphere as rain, snow, rivers, streams, groundwater, lakes, seas, oceans, and water vapour. Urban Canada uses large quantities of water that eventually finds its way back into the cycle carrying some form of impurity.

Although contaminants may seep into urban groundwater supplies, the surface water of lakes and rivers is particularly susceptible to contamination from such diverse sources as industrial and municipal effluents, agricultural runoff, and acid rain. Toronto and most of its immediate neighbours, for example, draw water from Lake Ontario, which has been seriously polluted. And in the Montreal, Quebec City, and Lac St-Pierre regions, half of the tributaries of the St. Lawrence River are severely degraded (Ministère de l'Environnement du Québec 1988). Although this large-scale deterioration is by far the most serious water quality problem that cities face, urban water quality can also be affected by the distance the water must be piped to the city: the water pipes themselves may be old, leaky, corroded, and, in the case of some old mains, made of lead.

To meet health standards, urban water supplies are treated to remove or neutralize dangerous substances, such as bacteria and chemicals from industrial discharges. Minerals may also be removed to soften the water for washing purposes. Some industries have to further purify the water in order to meet their own specialized requirements. The Canadian Water Quality Guidelines are currently being revised to include many more substances that are now found in water supplies and that may have adverse health effects (Canadian Council of Resource and Environment Ministers 1987). Lakes and rivers, however, cannot be treated, and, in some cases, cities must restrict swimming and recreational fishing to safeguard human health.

Excessive water consumption

Canadians are profligate water users: at 360 L daily, Canadian per capita water consumption is the second highest in the world. Extravagant water use is encouraged by water pricing policies in Canada: 37% of the people pay a flat rate for water regardless of the amount used, whereas 34% actually pay a decreasing unit price as their consumption rises (Tate 1990). In fact, the costs of treating, pumping, and distributing fresh water far exceed what Canadians pay.

A more realistic pricing policy would encourage efficient water use and conservation in those areas where it is a major issue, such as in communities that are dependent on limited groundwater supplies. In other areas, there would be a reduced need to disrupt natural water systems to increase supply. By attaching a greater value to the resource, appropriate pricing may even discourage pollution of water and provide increased revenue to maintain, repair, and replace treatment and distribution systems. Planning guidelines and research and development would also help provide technical and social options for efficient water use and for shifting to new processes that are less polluting overall, such as water recycling systems.

Sources of water pollution

After it is used, water leaves the city primarily as municipal sewage, as industrial wastewater, and as runoff. All three are serious sources of pollution.

Municipal sewage

Municipal sewage is a principal source of water pollution (Pearse *et al.* 1985), chiefly because much of it is untreated or inadequately treated (Figs. 13.7 and 13.8). A 1989 survey covering 86% of Canada's population revealed that 30% had no sewage treatment of any kind (Environment Canada, no date *a*). Even in the major centres of Montreal and Quebec City, some sewage continues to be discharged untreated into the St. Lawrence River, and coastal cities such as Halifax and Victoria discharge their sewage untreated into the ocean.

As well, quantities of sewage are high: in 1985, the estimated daily discharge of municipal sewage in Canada represented about 1 300 t of biochemical oxygen demand and contained 1 200 t of suspended solids (Pearse *et al.* 1985; Statistics Canada 1986). In Halifax alone, for example, some 200 million litres a day of raw sewage flows untreated into the harbour through some 40 sewage outfalls. The waters are often covered in algal blooms from excess nutrients and can be unpleasant to look at and to smell; they can also be dangerous to health. The harbour has elevated levels of fecal and other coliform bacteria and toxic chemicals in sediment. This, in turn, leads to beach closures and the curtailment of shellfish harvesting.

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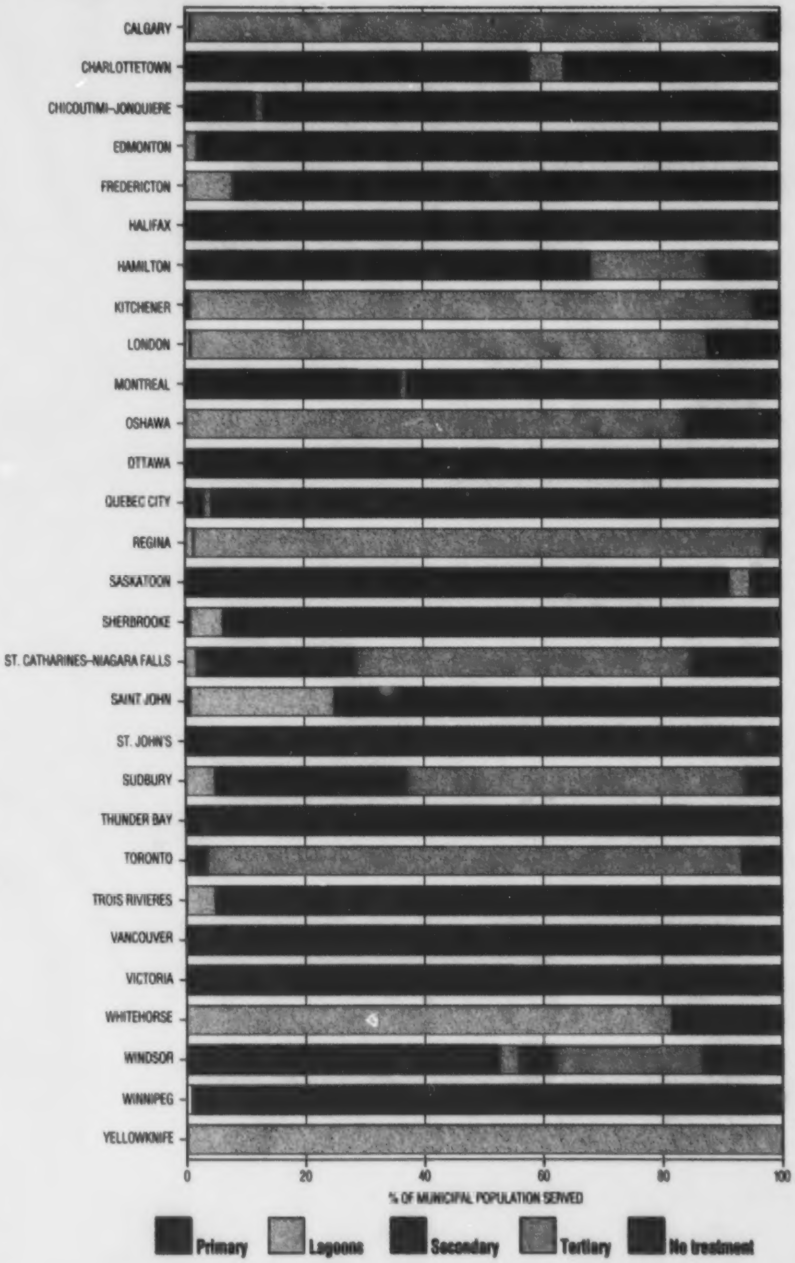
Municipal sewage treatment for selected urban centres, 1986



Source: Environment Canada, MUD/MUNDAT databases.

Fortunately, a $200-million federal–provincial program to clean up Halifax Harbour is under way. In 1988, $195.7 million was committed by federal, provincial, and municipal governments towards the design and construction of a regional sewage treatment system. Indeed, across Canada, the level of sewage treatment is improving. In most of the country, new urban developments customarily provide sewers, although not necessarily treatment. The city of Montreal has built a new treatment plant fed by over 100 km of interceptor tunnels along the north and south shores of the island. Also in Quebec, 614 municipalities — or some

5 million people — were engaged in programs to improve the quality of used water in 1987 (Ministère de l'Environnement du Québec 1988).

Despite these new programs, however, many existing treatment facilities are becoming increasingly inadequate: water mains, sewers, and treatment plants are aging and gradually deteriorating. In the older cities of eastern and central Canada, some water mains are now over 100 years old, and combined sewers carry both storm and sanitary sewage to treatment plants. During heavy rains, these combined sewers may overload the treatment facilities, so that both storm sewage and sanitary sewage are discharged untreated. Of the municipalities covered by a 1984 study, 10% reported that their water treatment facilities were unserviceable or in need of major repair, and 8% said the same of their sewage treatment (Federation of Canadian Municipalities 1984). Many were concerned that maintenance expenditures were insufficient and could not prevent a continuing deterioration of infrastructure. Some cities, such as Ottawa, are now setting up long-term capital funds to permit the gradual replacement of old water and sewer mains.

Industrial wastewater

Even where facilities are adequate to treat domestic or sanitary sewage to acceptable standards, industrial wastewater may be discharged directly into rivers and lakes. The wastewater is sometimes seriously contaminated: industrial pollutants can remain environmentally damaging even after passing through conventional sewage treatment (see Chapter 14).

Runoff

It is often possible to control industrial wastewater at the source, but surface runoff is particularly difficult to manage. Every house, lot, storm drain, car, and service station is a probable source of pollutants, and the quantity of runoff is enormously increased by the hard surfaces of the city. Surface runoff is commonly directed into storm sewers and thence, untreated, into the receiving lake or stream, bearing grease, oil, salt, garden fertilizer and pesticides, animal feces, and a variety of other contaminants. It is a major source of toxic metals, chlorinated organic compounds, and other serious pollutants. Eutrophic lakes and badly polluted streams in urban areas demonstrate the extent of the problem. Even when storm sewage is directed into treatment plants, heavy rainfall can overload treatment capacity.

Snow also contributes to surface runoff problems, because the concentration of pollutants in street snow is generally 10 times higher than that found in snow on grassed areas. Much of this contaminated snow ends up in surface waters. In 1983, for example, between 250 and 300 urban places in Quebec disposed of a total of 30 million cubic metres of snow, of which 64% was deposited on landfills, 29% in rivers and lakes, and 7% in sewers (Ministère de l'Environnement du Québec 1988).

Water pollution is also caused by the dumping of excavated material from construction sites, although this is a limited occurrence that constitutes a significant health hazard only when the material is contaminated. It can, however, harm fish spawning sites.

Curbing water pollution

Across the country, Canadians have initiated large-scale remedial programs to reduce the impact of the city on adjacent water bodies. The lower Fraser River, for example, flows through the most heavily urbanized and industrialized area in British Columbia and the third largest urban region in Canada. The river's estuary is contaminated not only by the region's sewage, industrial effluents, and runoff, but also by atmospheric and marine pollutants (see Chapter 16). The Fraser River Estuary Management Plan addresses these and other impacts on the Fraser River estuary that result from unplanned growth in the region.

The extensive contamination of the Great Lakes system (see Chapter 18) has led the Great Lakes Water Quality Board of the International Joint Commission to designate no fewer than 43 "Areas of Concern," 12 of which are wholly within Ontario. The list includes both Hamilton Harbour and the Toronto waterfront. In the Toronto area, water pollution control (sewage treatment) plants, sewers, contaminated sediments, and the atmosphere are all important sources of pollution. The Metro Toronto Remedial Action Plan, one of 17 under way in Ontario, has initiated programs to alleviate specific local problems.

Hamilton Harbour, or Burlington Bay, receives the industrial and municipal wastes and the urban and rural runoff from a watershed many times larger than the harbour itself. Thus, its remedial action plan must bring together not only the many agencies with relevant responsibilities but also stakeholder groups. The remedial action plan must consider existing threats to the many uses of Hamilton Harbour and the adjacent conservation and recreation area of Cootes Paradise.

The extreme complexity of achieving consensus to manage the marine environment is demonstrated in the case of Halifax Harbour. Following an expression of public concern over siting proposals for the regional sewage treatment system, the volunteer Halifax Harbour Task Force undertook a review and made 18 recommendations dealing with siting, treatment options, and public participation in the process. A candidate site has been chosen, and construction is due to begin in 1993.

To curb extensive pollution of the St. Lawrence River, the St. Lawrence Action Plan aims to eliminate 90% of the total toxic liquid effluent at 50 sites. Many of the sites are located in and around urban areas, notably Montreal. In the Federal Site Clean-Up, contaminant levels in sediment are being studied in Montreal, Trois-Rivières, and Quebec City harbours.

Despite these large-scale initiatives, the task confronting Canadians is very long-term. Cities and urban regions form critical points of concentration in the water cycle, in which extravagantly large volumes of water are drawn off, treated to make them reasonably safe for human use, and then fed back into the cycle in even worse condition. Ideally, water should leave the city with its quality unimpaired.

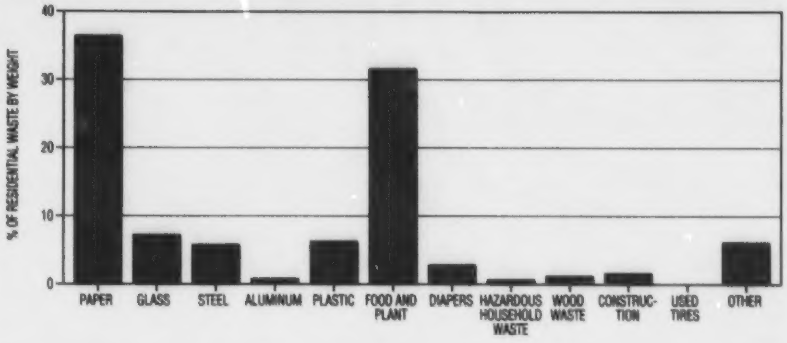
The city *per se*, however, is not the cause of water pollution: it is the activities of people. If city people were to disperse across the countryside and continue the same activities, neither water demand nor water pollution would be likely to decrease.

Using energy

Canadians are prodigal users of energy: on a per capita basis, they are the heaviest consumers in the world. In part, this is an unavoidable consequence of geography and climate: Canadians depend on energy for the very habitability of their cities. However, countries with similar climates use far less energy. In 1987, each Canadian used, on average, 291 GJ (gigajoules) of energy, compared with approximately 280 GJ in the United States and 194 GJ in the Soviet Union (World Resources Institute 1990).[2] Canada's high energy consumption, like its water use, is also a result of traditionally low prices permitted by a seemingly abundant domestic supply. This has promoted the growth of a substantial energy-intensive industrial sector, but it has also encouraged low urban densities, poorly insulated buildings, and energy-inefficient vehicles.

Pricing, together with government policy, can encourage efficient energy use, particularly if combined with research and development programs in energy conservation and alternative energy sources. Following the rapid rise in oil prices in the early 1970s, for example, the federal and provincial governments undertook a variety of measures to foster energy conservation and, in particular, to reduce reliance on oil. These met with some success. Between 1974 and 1982, average energy consumption per household dropped by 16%, and annual fuel oil consumption declined by 42 million barrels (Rostum 1987). In Quebec, it took only the two decades from 1966 to 1986 for average residential energy consumption to fall by half, as a result of home insulation programs and behavioural changes (Ministère de l'Environnement du Québec 1988). However, with the stabilization of oil prices, energy conservation became a much lower political priority. (For a more detailed discussion of energy, see Chapter 12.)

What we throw away: the composition of residential waste in Ontario, 1989



Source: Ontario Ministry of the Environment (in press).

Canadians remain wedded to two heavy energy users: the detached one-family house, and the car. However, it is not at all clear how cities affect these high-energy choices. Do the city size and structure encourage them through such mechanisms as cheaper suburban land prices and expressways leading to the city's core? Or are the single-family home and car individual choices, which the city decidedly discourages by providing social and recreational opportunities and efficient transit service in densely populated areas? The many conflicting influences are examined in some detail in a later section.

Using and disposing of materials

The city's built environment is shaped of materials, such as wood, steel, aluminum, bricks, concrete, and asphalt. Not only do these materials consume natural resources, but they must be produced and transported to the city, increasing energy use and air pollution. These building materials may even have adverse environmental effects when their use is ended, as when old lumber is burned or rubble is dumped in ravines or wetlands.

Construction aggregates are perhaps the most basic and ubiquitous of urban building materials, as they are a prime constituent of both concrete and road construction. Because so much sand and gravel is needed and because the aggregates are expensive to haul, pits and quarries are common features of the landscape on the fringe of urban areas. In 1976, they occupied nearly 25 000 ha of land around cities of more than 100 000 population (Environment Canada, no date *b*). In 1977, a more detailed survey carried out for Environment Canada that examined eastern Canadian sites around urban places of 500 or more found 4 997 sites totalling 34 072 ha (Marshall 1982). These sand and gravel operations generate dust, noise, and heavy truck traffic. In many cases, they destroy good farmland, woodland, or other natural features, and they are usually visually offensive unless well screened. Worked-out quarries and gravel pits are sometimes — by no means always — either restored to agricultural use if the topsoil has been saved or converted to recreational use (see Chapter 11).

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[2] One gigajoule is approximately equivalent to a 30-L gasoline fill-up.

Construction materials, however, constitute only one category of urban consumption. A wide variety of materials is required to meet the needs of urban populations: products from carpets to computers, from toilet paper to telecommunications equipment. Some have a useful life measured in decades, but for most it is much shorter; virtually all cease to be regarded as useful sooner or later. At that point, they become scrap or garbage (Fig. 13.9).

Not very long ago, all wastes — including industrial and toxic wastes — that were not habitually incinerated were simply dumped, either into convenient ravines or disused quarries or at sea. Although such practices are coming to an end, old abandoned hazardous waste dumps still exist, and the dangers to health and safety remain. Also, a number of problems persist: land and water can be contaminated by leakage from existing hazardous material storage containers (such as underground oil storage tanks), by illegal dumping, and even by waste processing facilities. Toxic materials still abound in commercial and consumer products, most of which eventually end up in the general waste stream.

With the advent of the consumer economy, this waste stream has undergone massive growth and now incorporates plastics, "throwaways," and enormous increases in the amount of packaging. Canadians have become the world's leading producers of waste. In 1989, we generated 20 million tonnes of solid waste, or nearly 2 kg per person each day (MacLaren Engineering 1989). Every day, Metropolitan Toronto sends 8 905 t of waste material to landfill sites or incinerators (City of Toronto 1991).

Many urban areas are running out of space for sanitary landfills. The search for new sites is complicated by land-use conflicts and by the virtual certainty that residents will strongly oppose potential sites in their areas: the so-called "NIMBY (not in my back yard) syndrome." This reluctance to harbour waste sites stems in large measure from the dangers posed by toxic materials. These wastes seriously limit the choice of suitable sites. To protect public health and the environment, it is essential to prevent toxic chemicals from leaching into groundwater. There are not enough comprehensive data to provide a national picture of the leaching problem, but, given its irreversibility (with present technology) and the implications for human and ecosystem health, it is of prime concern. If a suitable landfill site can be found, engineering solutions such as lining it with clay can be effective, but these are not foolproof (see Chapter 21).

Modern incineration may be an alternative to landfills, but it, too, encounters strong public opposition, due at least in part to the potential impacts of toxic ash emissions. As toxic wastes are so difficult to dispose of, the best solution is to reduce the quantity that enters the waste stream, both by lowering the levels of toxicity in consumer products and by separating out hazardous materials in the waste management process.

The quantity of solid waste can also be reduced at source, by cutting back on packaging, for example, and through the reuse and recycling of materials. Programs to encourage these measures, such as the curbside Blue Box program and residential composting programs, have been well received by the public, demonstrating that individuals are prepared to change their habits in support of the environment. Thus far, however, these programs have had only a marginal effect on the volume of solid waste, and several key problems remain. Better markets must be developed for recycled materials, such as newsprint, if the expense of recycling programs is to be reduced. As well, such publicly accepted recycling programs may discourage more appropriate and cost-effective reduction and reuse strategies (see Chapter 25). Canada's excess production of waste, like the country's excessive consumption of energy and water, is due at least in part to pricing policies. To stimulate better strategies, the cost of waste management should be built into the price of consumer products.

The waste management issue is virtually a paradigm of the basic dilemma of a wealthy, industrialized, urban society: how to reconcile continuing economic growth and material prosperity with protection of the environment and conservation of resources for future generations. Again, however, waste management is not a problem created by urbanization. Undoubtedly, it has become a very serious problem *for* cities, because it is *in* cities that large numbers of waste sources are concentrated and hence large volumes of waste generated. But the waste is produced by people and their businesses and industries. There is no reason to suppose that the total volume would be lower in another setting. In the city, on the other hand, collection, recycling, and other aspects of waste management are relatively economical.

The city's place in the ecosystem

The city plays a critical role in the flow of air, water, energy, and materials in the ecosystem, using and often polluting them before returning them to the ecosystem, transformed. However, urbanization in itself is not the environmental evil that it is widely assumed to be. People and their activities foul air and water, use energy and materials, and create waste. Only in a few respects, such as runoff from paved surfaces and the creation of photochemical smog, does the urban environment itself contribute to these processes. Although the concentration of pollutant sources and the generation of wastes in urban areas certainly make these problems more evident and, in some cases, more dangerous to human health, the problems are also more readily dealt with in urban settings.

Rather than urbanization, the problem is consumption, with the demands it places on all resources and with the corresponding level of waste to be absorbed by air, water, and land. In addition to the amount of resources and energy we use, there is the question of how they are used. Technologies and processes do not necessarily take into account the functioning of natural ecosystems. These problems stem from the choices Canadians make — how and what we produce and consume, and how we manage wastes. The most telling example is our dependence on the car, which is the prime generator of air pollution, a major source of other forms of pollution, and a leading consumer of energy and material resources.

URBAN FORM AND THE ENVIRONMENT

Urban growth and change

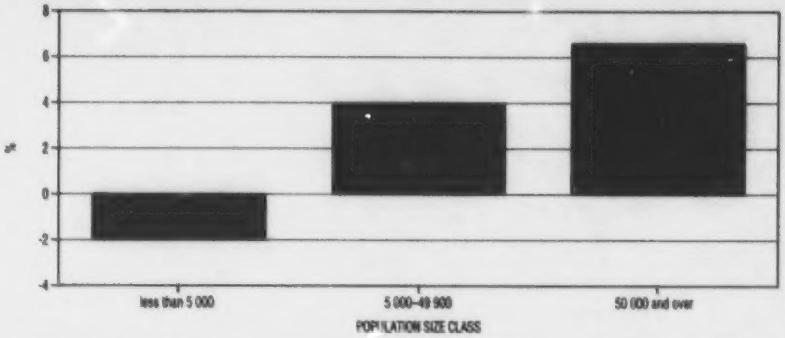
Growing urban populations

During the present century, Canada's urban population has increased 10-fold, from less than 2 million to 19.4 million. Virtually all cities are growing, but Canada's population is increasingly concentrating in the country's largest cities.

This growth pattern, however, has not always been consistent. Although Canadian cities rapidly expanded in the post-World War II period, the growth rate of the largest cities began to decline in the 1960s. By the 1970s, the smaller urban centres were growing more rapidly than the larger ones. By the early 1980s, the largest cities once again experienced the most rapid growth. The smallest urban places with populations of 30 000 actually declined in size (Robinson 1981; Simmons and Bourne 1984, 1989).

Canada's population, then, is not just becoming more urban: it is also becoming more metropolitan. Figure 13.10 shows the higher growth rates of the larger municipalities in the 1990s. In 1951, fewer than 4 in 10 Canadians lived in cities of 100 000 or more; by 1986, the proportion was over 6 in 10. The total population of these large cities more than quadrupled, from 3.4 million to 15.2 million. This accounts for almost all of Canada's urban population growth during that period (Mitchell 1989). The 1986 Census of Canada demonstrated that nearly a third of all Canadians live in three metropolitan agglomerations: Toronto (3.43 million), Montreal (2.92 million), and Vancouver (1.4 million).

Population change by municipal size, 1981–86



Source: Mitchell (1989).

The shape of the city

Population growth, together with demographic and economic change, affects the city's structure as well as its size.

The typical Canadian city has a densely built-up central business district of office buildings, retail businesses, and hotels. This is surrounded by a complex transition zone, which includes relatively old residential buildings, in many cases converted to other uses; often obsolescent and sometimes vacant warehouses and industrial premises; parking lots; and a variety of institutional, commercial, and personal services. In thriving cities, such as Toronto and Vancouver, prosperity is bringing about the continuous redevelopment of the central core: a succession of new office buildings and hotels is almost completely displacing other kinds of buildings (except department stores and enclosed shopping malls) and expanding from the core area into the transition zone.

Increasingly, office buildings in the central business district house head offices and associated professional and technical services. Ancillary business operations, such as records and information storage, are moving to outlying subcentres and even outside the city, as the necessary linkages can be provided by information and communications technology rather than by physical proximity. Industries and even retail businesses are leaving the congested inner areas for more spacious suburban sites. This is part of a major metropolitan functional decentralization, as white-collar employment migrates to suburban office campuses and new metropolitan subcentres. Toronto and Montreal, for example, are increasingly embracing dozens of outlying communities, and urban commuters form daily business linkages and seek entertainment and even education throughout the entire metropolitan area.

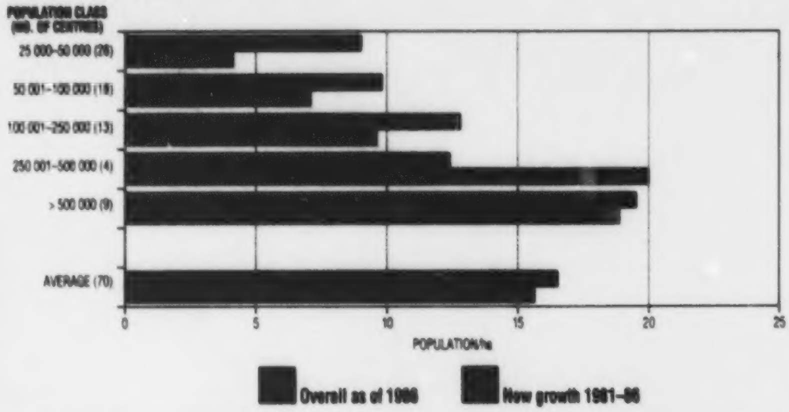
Beyond the central business district and the transition zone, the urban area is primarily residential, interspersed with industrial tracts. The inner and older residential areas are usually more compactly built than the outer and newer districts, with smaller lots and often a substantial admixture of multiple-unit buildings. In the relatively new areas farthest from the core, single-family houses predominate (except in Quebec).

Changing densities

As Canadian cities grow outward, average population densities decline (Fig. 13.11). The tightly knit cities of earlier days, based on transit networks radiating from the central business district, have given way to today's car-oriented pattern. This decentralization

FIGURE 13.11

Urban density trends: existing density versus density of new growth in centres by population size



Source: Derived from Warren *et al.* (1989).

has been reinforced by zoning, which usually encouraged the development of extensive tracts of unvaried, low-density housing. Thus, from the 1930s through the 1970s, densities declined continuously. This was generally accompanied by a steady migration of residents from the older residential areas to the newer suburbs, while recent immigrants took over the older areas.

In the 1980s, however, the overall decline in density appeared to have been slowed. A drop in average household size, including an increase in the proportion of one-person households, was accompanied by a rise in the number of apartments, particularly in the large cities, so that, in 1986, 30.3% of all dwellings were apartments. Row housing also became more common, especially in eastern Canada, although row units still accounted for only 4.1%, and semidetached and duplex units 8.1%, of dwellings (Canada Mortgage and Housing Corporation 1989).

In Toronto and Vancouver, in fact, a countertrend back to the inner city developed, as middle-class business and professional people chose the convenience of centrally located apartments and renovated houses in the transition zone and older residential areas over suburban lawns and shopping malls. The same pattern is evident in Montreal, although the change is not as dramatic.

As a result of this trend, new rental and condominium apartment buildings are appearing in the core area itself and in existing nearby high-density residential areas, such as Vancouver's West End. Some inner cities are experiencing a renaissance: formerly modest and even near-slum residential areas are undergoing gentrification, and new neighbourhoods are developing in former commercial and industrial areas, such as Toronto's St. Lawrence neighbourhood and Vancouver's False Creek.

As these areas are converted to new uses, so are ports and even railway yards in cities such as Toronto, Montreal, Halifax, Vancouver, and Winnipeg. These conversions offer cities an opportunity to bring residents back to the inner city and sometimes to provide financially assisted and moderate-cost housing. Other cities convert the area to green space, as with Montreal's Lachine Canal and Winnipeg's Forks area. An initially unexpected obstacle, however, has been the discovery that such sites are frequently so contaminated by residues and wastes from their previous uses, including lead, petroleum derivatives, and PCBs, that they present health hazards to permanent residents. Some such sites are even considered unsafe for commercial, recreational, and other less-than-full-time use. One possible solution is excavation and removal of the contaminated soil, but this raises the new problem of finding a satisfactory means of disposal.

Taken together, these activities check the trend to depopulation of the inner areas of the cities. However, the figures on new single-family house construction bear witness to the continuing attraction of the low-density suburb in cities outside of Quebec (Canada Mortgage and Housing Corporation 1990).

Contradictory trends in transportation

During the 1950s and 1960s, both Toronto and Montreal encouraged city spread, and the related use of cars, by building expressways. While they were building expressways, however, both cities were also building new subway systems, which have since been substantially extended. Other cities, such as Ottawa, Edmonton, Calgary, and Vancouver, have adopted different technical solutions: Ottawa's bus transitway is an example. Whatever form it takes, however, the public transit option now seems to be the cities' preference: the era of urban expressway construction seems to be coming to an end in Canada, although there are still pressures to continue expressway expansion. Public transit is more cost-effective, less disruptive, and more environmentally benign. It does not necessarily follow, however, that the city politicians will frame policies that favour transit use. The Quebec government, for example, is trying to disengage itself from urban transit and pass the financial burden on to the municipalities, which do not have adequate fiscal resources. For the foreseeable future, the private car will remain the commuter's transportation mode of choice — partly for reasons of urban form. The prospect for cities generally seems to be one of growing traffic congestion, with all its implications for air pollution and fuel consumption (see Box 13.1).

BOX 13.1

Intra-urban transit

Cars are major producers of air pollution and greenhouse gases. They have various other negative environmental impacts and are intensive energy users. One study estimates that the total energy expenditure related to the car could account for up to 50% of all energy use in developed countries (Gagnon 1989).

Given the magnitude of environmental stress that can be related to the private automobile, a focus on mitigating its impact could have major results. Indeed, an overall fall in ambient levels of nitrogen dioxide and carbon monoxide over the past 15 years can be attributed to improved fuel efficiencies and pollution control devices in motor vehicles. In recent years, however, this decline has slowed and nitrogen dioxide levels have actually increased. This is likely due to the general increase in the use of private automobiles in Canada (Fig.13.B1), despite an accompanying marginal increase in public transit use.

The improvement in efficiency of the private automobile, then, can be outweighed by the growth in its use. Research and development in the use of alternative fuels and technologies can result in further efficiencies. Progress will be realized, however, only if the trend of increasing reliance on the car for transportation needs is reversed or levelled. It is important, then, to encourage the use of alternative transportation methods that are known to have less negative environmental impacts.

The main alternatives to the use of the car for intra-urban transportation are public transit, walking, and other less popular modes, such as bicycle, motorcycle, and taxi. The relative environmental impacts of these alternative transit modes can be compared on a passenger per kilometre basis. A city bus during peak travel periods will produce approximately one-eighth the amount of nitrous oxide, one-half the amount of carbon monoxide, and one-sixth the amount of VOCs (Canadian Urban Transit Association 1986). Walking and bicycling are, of course, virtually pollution-free. Energy consumption (and the related release of carbon dioxide) is also much lower for public transit than for private automobiles (Fig. 13.B2).

The reliance of Canadians on the car is overwhelming. In 1980, out of 9.2 million commuters, 6.8 million commuted via 5.7 million private automobiles (Statistics Canada 1982). The present trend for use of alternative transportation modes and the heavy reliance on the private automobile (on a per commuter basis) show little change over time (Fig. 13.B3). Nor has the price of gasoline had a perceptible influence. Between 1983 and 1984, for example, there was a 4% increase in the number of commuters using automobiles to get to work in spite of a 7.4% increase in gasoline prices (Statistics Canada 1984).

The continued dominance of the car is partly due to the prevalence of low-density suburban developments. The environmental advantages of public transit, as well as its practicality, are diminished in these low-density settlement areas — especially if the frequency of service approaches the kind of convenience possible when using a car. It may be that, in low-density areas, car- or van-commuting schemes would be the more efficient transit modes (Reid 1986).

An Australian study of cities around the world showed that the tendency to use public transit is greater in cities of higher density (over 40 people per hectare) (Newman *et al.* 1988). Indeed, in the larger Canadian cities (where there are more extensive high-density areas), public transit is more developed, and ridership, per capita, is relatively high compared with smaller centres (Fig. 13.B4). The four urban centres with the highest percentages of public transit ridership in 1980 were Toronto (31%), Ottawa–Hull (29%), Montreal (27%), and Winnipeg (25%).

The tendency to shift to alternative transit modes would seem to be dependent on appropriate structures and settlement patterns. In this light, a general strategy might be to guide urban growth and development to favour higher densities. More specific strategies might include improving public transit systems in high-density areas and creating and improving facilities for walking and cycling to increase the attractiveness of these options.

A rational approach to integrating transit modes to match the existing settlement patterns could also maximize environmental benefits. For example, controlled access by cars to high-density areas and efficient interfaces with mass transit (i.e., park and ride) would encourage the use of mass transit in core areas. A recent poll suggests that a majority of Canadians are in favour of at least a partial ban on driving in the downtown core (Thompson, Lightstone & Co. 1990).

These and other strategies would create an access structure for cities based on efficiency and environmental priorities rather than providing infrastructure for automobiles. The choice between driving a car through sluggish traffic and jumping on an express bus on a dedicated lane would become more obvious.

Environmental implications of the urban structure

The complex dynamics of these changes in urban structure make it exceedingly difficult to tally the environmental impacts of today's cities. In the absence of systematic study or even, for the most part, recent baseline data, much can only be the subject of surmise and informed guesswork. On this basis, a few observations can be made.

- The growing acceptance of relatively high-density dwellings — from apartments to renovated, old inner-city homes converted to multiple occupancy — is generally environmentally positive, as it reduces land consumption, increases fuel efficiency, and promotes transit use. However, land-use conflicts can occur, and the gain is probably small in relation to the resource demands of the still-prevalent single-family homes. Many of these widely spaced detached houses are even being rebuilt or replaced by substantially larger single dwellings.

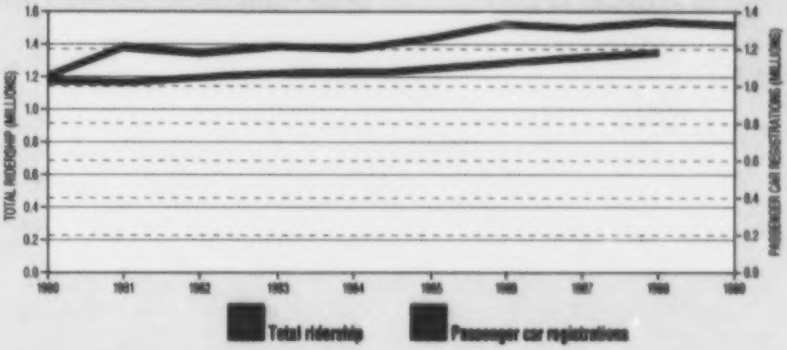
- The expansion of the big-city central business district through the redevelopment of surrounding blocks frequently means the replacement of old buildings of historic or architectural interest and distinctive character by anonymous, massive commercial structures. This often creates a streetscape that is visually overpowering, charmless, and subject to concentrated air and noise pollution. Internally, the working environment is often impersonal, enclosed, and artificially ventilated. The physical and psychological effects of this type of built environment require much more attention than they have so far received (see Box 13.2).

- Cities have characteristically zoned large areas exclusively for a single use and often for a single type of building, such as residential areas composed solely of detached houses. Similarly, large buildings or building groups were restricted to either offices or apartments, perhaps with shops on the ground floor. From an environmental standpoint, this practice was at one time justified: it segregated polluting or otherwise offensive industries into remote enclaves. As cities grew, however, this type of zoning encouraged the wide separation of different use areas and thus increased total travel distances. The practice is now giving way to the mixed-use principle, which encourages more intensive day-and-evening site use and reduces travel needs. A mixed-use development can include offices, stores, apartments, and recreation and entertainment facilities. It is typically located in a highly accessible area or serves as a new "town centre."

- With the advent of the "wired city," business and even such domestic activities as shopping can be increasingly conducted by means of information technology rather than in person. This should reduce travel needs and, in the long run, free urban planners from traditional constraints, allowing the city to take forms better related to environmental considerations. However, the issue is a complex one, and the dynamics of the wired city are still by no means clear. In practice, the effects may be much

FIGURE 13.01

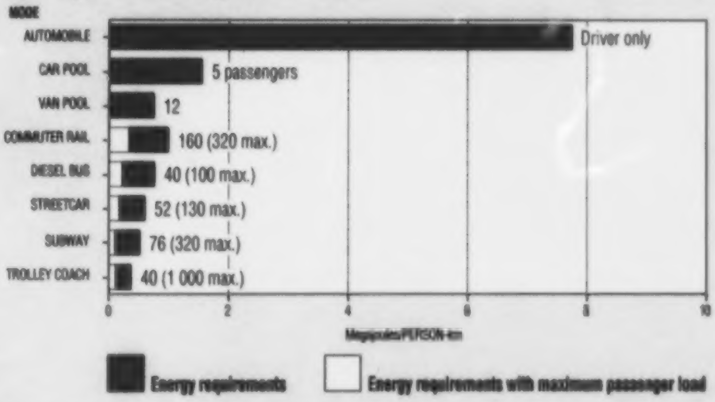
Car registrations and transit use



Source: Canadian Urban Transit Association, Statistics Canada.

FIGURE 13.02

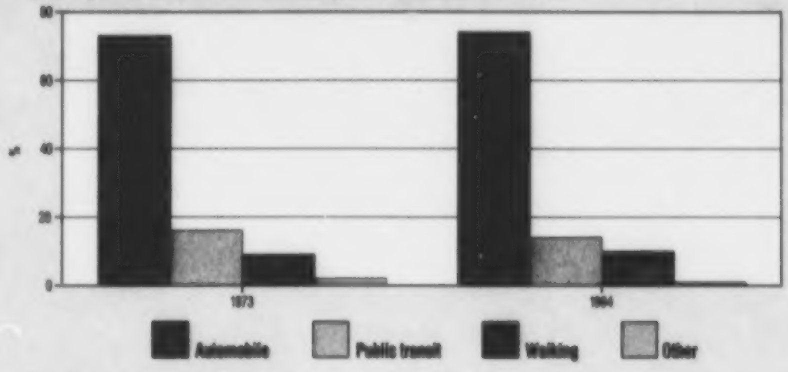
Energy requirements by transit mode



Source: Ontario Ministry of Transportation and Communications (1983).

FIGURE 13.[illegible]

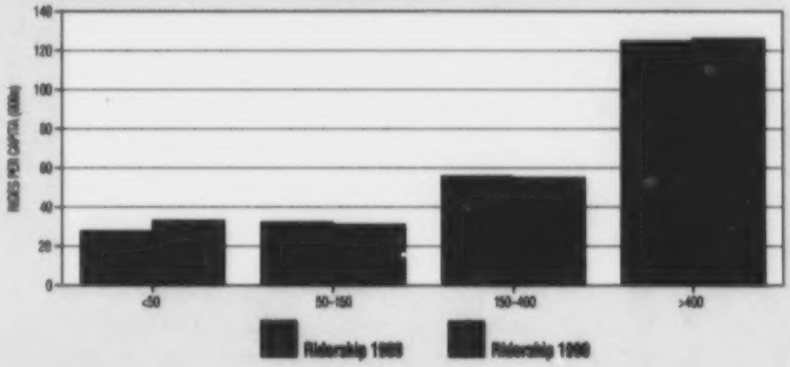
Primary modes of commuting in Canada



Source: Statistics Canada.

FIGURE 13.14

Urban transit rides per capita by community size



Source: Canadian Urban Transit Association.

less dramatic than the technical potential might suggest, especially if planning fails to take advantage of contemporary technology.

Single-family homes: an environmentally expensive luxury

The growth pattern of Canadian cities owes much to the Canadian desire to own a detached dwelling on its own parcel of land . (The Province of Quebec is a partial, but only a partial, exception.) This profound conviction, probably originating in the historical archetype of the settler's log cabin built in the middle of the land he has cleared, is reinforced by the social and psychological values of privacy, identity, and outdoor space. Home ownership is also traditionally associated with financial security — a link encouraged for at least four decades by government policies.

In 1990, despite rising mortgage rates and the fact that close to half of all households consisted of only one or two people, single detached houses still accounted for 53.4% of all dwellings on which construction began (Fig. 13.12). Even in the 25 largest urban areas, 43% were single-family homes; in Edmonton and Calgary, the proportion was as high as 86.7% and 87.2%, respectively. Only in the cities of Quebec were single detached housing starts consistently outnumbered by other types of dwelling (Canada Mortgage and Housing Corporation 1990).

City dwellers who favour single detached housing in the low-density suburbs are consequently dependent on the private car. In 1987, 77% of all households owned one or more cars, and, according to a 1983 survey, 73% of all journeys to work were made by car (Rostum 1987). Figure 13.13 shows that the majority of commuters live over 3.2 km from their work. Ironically, however, car use does not depend solely on distances to work. In 1980, even at a distance of less than 1.6 km, 39% of commuters still used a car (Statistics Canada 1982). A second car per household is usually considered equally necessary, either for the use of a second breadwinner or to take the kids to school and hockey practice and to visit the supermarket.

One explanation for increased dependence on the fossil-fuel-consuming, carbon-dioxide-emitting automobile is that frequent, convenient transit service is generally not economically feasible in the suburbs. Economical transit depends on high population densities, and even relatively compact new suburbs accommodate only 30 persons or so per hectare. Even in the Greater Toronto area, however, despite the availability of an efficient transit system, 64% of commuters use cars (City of Toronto 1991), and the volume of motor traffic is growing by 6% annually (Ontario Ministry of Transportation and Communications, no date).

The environmental impacts of suburban living are not restricted to the suburbanites' dependence on the car. The detached house, even when well insulated, requires more energy for heating than do more compact types of dwelling. Low suburban densities also mean high energy consumption for such services as snow removal. In summer, air conditioners and power lawn mowers add to energy demand, and lawn sprinklers raise water consumption. Also, the ever-expanding lateral spread must be continuously provided with new roads, water mains and sewers, whereas the intensification of land use in older areas makes use of existing services.

In short, the single-family subdivision that now houses a large proportion of the Canadian population imposes a considerable burden both on Canada's natural environment and on its resources. At the same time, it concentrates these problems within a boundary in which they can be successfully addressed. With the increasing public awareness of these problems, together with the human capacity to resolve them, communities are beginning to implement decisions to address these problems.

The demand for space: urban spread

Urbanizing the land

The growth in population and in the number of households, particularly those occupying detached houses, in Canadian cities creates a continuous demand for space to build new dwellings and community facilities. Economic growth creates a parallel demand for industrial and commercial sites, all requiring roads and a variety of other supporting infrastructures. Much of this demand for space occurs in the fast-growing larger urban areas. For instance, the already strong population growth pressures and competition for land in the Quebec City to Windsor corridor, which now houses more than half the population of the entire country, continue to intensify. On a smaller scale, British Columbia's Lower Mainland is experiencing similar pressures.

BOX 13.2

The environment indoors

We tend to think of the urban environment as the built-up areas, green spaces, waterways, and the atmosphere that surround us when we are outdoors; but the walls, furniture, air, microbes, toxins, and so on, that are found indoors are no less part of it. In fact, as a species, our main habitat happens to be inside buildings. Canadians spend up to 70% of their time indoors on average, and, for some, this percentage can be much higher (Health and Welfare Canada 1989).

There are reasons for concern about indoor air quality. One trend is towards tighter building construction to increase the efficiency of heating and cooling; it is, ironically, a management response to the environmental issues of high energy use, air pollution, and global warming. The implications for the indoor environment, however, are that the rate of air exchange in buildings is much less, and air contaminants tend to linger and accumulate rather than be diluted and flushed outside.

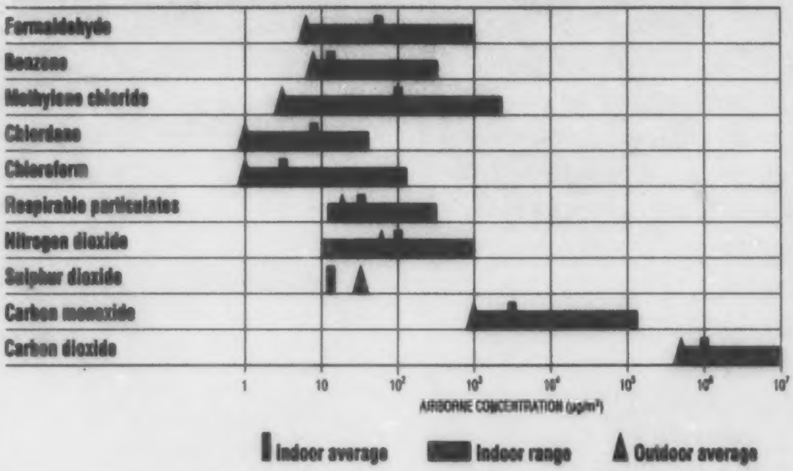
The sources of contamination of the indoor atmosphere include an increasingly complex array of synthetic chemicals used in building materials, furnishings, and consumer products. "Gassing off" from these sources releases volatile organic chlorides and other chemical vapours. Another class of contaminants comes from the fungi and bacteria present in buildings and other natural sources of allergens, such as house pets and dust mites (Day 1990). Tobacco smoke is another source of indoor air pollution.

Although it is difficult to link human health to specific indoor air contaminants, it is clear that degraded indoor air quality has an adverse effect. Symptoms of tiredness, lethargy, headache, and nausea, or "sick building syndrome," have been associated with particular building environments (Burge 1990). The long lifetime exposures to indoor contaminants that people are receiving mean that the effects are cumulative and very difficult to detect. The problem is also quite pervasive: there are at least 22 different types of indoor air pollutants that originate outdoors and indoors (Spengler and Sexton 1983). As shown in Figure 13.B5, the concentrations of many of these pollutants tend to be higher indoors than outdoors (Spengler and Sexton 1983; Nero 1988). Although more study may be required to determine precise cause–effect linkages, significant human and economic (i.e., health care) costs can be assumed to be attributable to indoor air quality.

Managing indoor air quality can be achieved in two ways: (1) by reducing the sources of air contamination, and (2) by improving the effectiveness of ventilation systems (without compromising energy conservation goals). For example, low-emission building materials and user-controlled passive ventilation could be incorporated into building design. In fact, an integrated approach to new buildings and building renovation could attempt to incorporate environmental, human health, and energy conservation goals into the design process. A task force of the Royal Architectural Institute of Canada will be considering the problem in this vein by examining the elements of healthy building environments (Anonymous 1991).

By 1986, two-thirds of Canada's population lived in its largest 70 cities (population over 25 000). In the preceding two decades, these cities spread onto more than 3 000 km² of surrounding land. Although the rate of this urbanization fluctuated over time, generally matching economic conditions, it was most rapid between 1966 and 1971. In the latest period monitored, from 1981 to 1986, 552 km² were converted from rural to urban use. Two-thirds of the land area converted lay around nine urban places with populations of more than 500 000. However, these large cities actually occupied "new" land much more economically than the smaller towns, using an average of

Indoor and outdoor air concentrations of selected pollutants



Source: Nero (1988).

53 ha per 1 000 population growth, compared with 242 ha per 1 000 for urban centres with populations between 25 000 and 50 000 (Fig. 13.14). The large centre's more intensive land use is probably attributable to higher land costs in these cities, as well as to the urbanites' dependence on transit use and the wish to avoid longer journeys to work. The large city's planning measures might also be firmer.

The rural–urban fringe

In both large and small urban areas, the cities' traditional central focus has given way to a dispersed pattern. Urban growth has created an extensive zone that is neither urban nor truly rural: the "rural–urban fringe." Included in this fringe are land uses and activities that are really urban adjuncts. They require low land prices, large site areas, relative isolation, and rural amenities. These range from recreation areas and "estate" residential developments to industrial and commercial operations, waste disposal sites, and gravel pits.

This trend towards deconcentration is reflected in the continuing increase in the "rural nonfarm" population (matched by a steady decline in the farm population). By 1986, 5.1 million people, or 20% of the country's entire population, were classified as rural nonfarm. Many of these people are essentially city-oriented in occupation and way of life; some commute long distances to city jobs (Statistics Canada 1986).

Although this kind of settlement can put pressure on natural resource lands and can result in less efficient transportation patterns, there is a proportion of this not-quite-urban population that is composed of good environmental stewards. Well-tended private woodlots, private wilderness reserves, or organic hobby farms can, for example, actually be environmental assets. Land-use and environmental pressures are brought about when urbanites bring with them less than environmentally benign behaviour to their once-rural surroundings.

The fringe zone extends far beyond the edge of the fully urbanized area. In 1981, for example, a land census of subdivisions in the Quebec City to Windsor corridor identified 34 000 km^2 as semiurban: that is, settled at a density of 25–60 persons per square kilometre (Yeates 1985). This far surpasses the area occupied by urban centres proper, at 27 000 km^2. (Rural areas accounted for 115 000 km^2.)

In Alberta, regional planning commissions have long been effective in controlling haphazard spread, whereas British Columbia and Quebec have laws controlling the conversion of farmland to nonagricultural uses (British Columbia Land Commission Act 1973; Quebec Act to Preserve Agricultural Land 1978). However, the low-density peripheral accretion and piecemeal fringe development have occurred because most provincial governments and municipal councils have been unwilling to impose firm controls on fringe land use. In municipal plans and zoning bylaws, "rural" and "agricultural" designations tend to be temporary and fairly readily amended, if they exist at all.

Loss of agricultural land

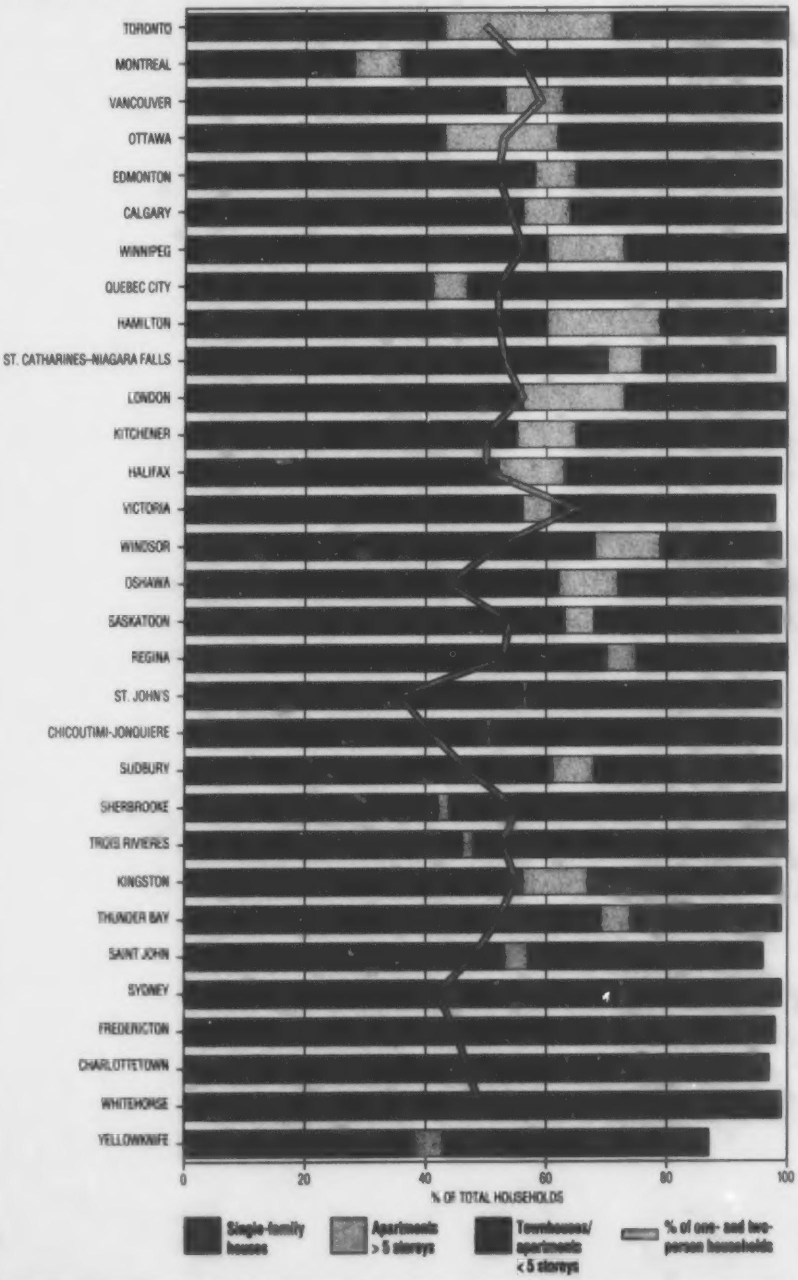
The reluctance of governments to regulate fringe growth has unfortunate resource and environmental consequences. Probably the most publicized and certainly the source of greatest public concern is the loss of good agricultural land.

Despite Canada's vast size, only about 5% of its total area is capable of producing a range of crops (Canada Land Inventory 1976). Farmlands were an important factor in the founding and early growth of most of Canada's principal cities — and, in some cases, their very *raison d'être*. However, the topographic, soil, drainage, and climatic conditions that favour agriculture also facilitate building. As a result, most of these cities, as well as hundreds of smaller towns, were born and continue to grow on the country's very limited supply of productive agricultural land (Warren *et al.* 1989).

The Canada Land Inventory puts the land-use dilemma in perspective. Of the top three classifications of agricultural land (CLI classes 1–3), a quarter is located within 80 km of Canada's

FIGURE 13.12

The dominance of the single-family house: percentage of dwelling type and one- and two-person households, 1986



Note: The difference between total % of dwelling types and 100% represents other dwelling types, such as mobile homes, residences, etc.

Source: Statistics Canada (various dates).

largest 23 cities. Of Canada's prime agricultural land (CLI class 1), however, more than half is in this near-urban area (Neimanis 1979). Thus, in the 20 years of urban growth from 1966 to 1986, large Canadian cities (of 25 000 or more) spread chiefly onto agricultural land: of the 301 440 ha of rural land urbanized, 58% was of high agricultural capability. And in the provinces of Ontario, Manitoba, and Prince Edward Island, the proportion was well over three-quarters.

Once agricultural land has been built on or otherwise modified for urban use, future agriculture is generally precluded, as a result of the removal or compaction of topsoil, the alteration of natural drainage, and other physical changes, as well as the sheer cost of rehabilitation. Agriculturalists cannot simply occupy lands more remote from the city, because soils and climates are less suitable and transportation costs are higher (Warren *et al.* 1989).

While urban conversion of prime agricultural lands is certainly a concern, it still represents only a small portion of the total stock of such lands (less than 1% between 1966 and 1986). The physical spread of metropolitan suburbs is only the visible tip of the iceberg, however. Urbanization also has an indirect impact, sometimes known as the "urban shadow" effect (Gertler *et al.* 1977). In the urban shadow, land tends to be seen as a potential site for urban use rather than as an agricultural resource. Land in the urban shadow may have inflated market value as a result of the actions of absentee land developers and speculators. Land-use conflicts are more common, and taxes are higher. These factors combine to undermine viable agriculture. Long before the bulldozers move in, farmers are discouraged from long-term planning and from making capital investments. The shadow's effects encourage soil mining, as long-term productivity is unlikely to be important (Martin 1975; Gierman 1977). Although little systematic research has been done on the geographical extent of the urban shadow effect, it certainly reaches at least as far as the rural–urban fringe zone and, in some respects, well beyond. Correspondingly, its effect on farming is far more widespread than is the actual conversion of farmland to urban uses (McCuaig and Manning 1982).

Loss of wetlands

The impacts of urbanization on Canada's natural resources are by no means confined to agricultural land. For example, wetland areas in the vicinity of major cities have been greatly reduced; reclamation for agriculture is partly responsible, as well as urban growth (Environment Canada 1988). Since 1950, wetlands have been steadily dredged, drained, and filled for port, industrial, and airport use, waste disposal, and urban growth in general. By 1981, up to 98% of the wetlands in the Regina, Winnipeg, and Windsor areas, 88% in the vicinity of Toronto and Montreal, and nearly 78% in the Vancouver, Calgary, and St. Catharines–Niagara Falls areas had been converted to other uses. Yet these scarce wetlands near cities are of particular value to urban residents for education and recreation, as well as for wildlife habitat and groundwater storage. Wetlands can also act as an effective filter, contributing to cleaner surface waters.

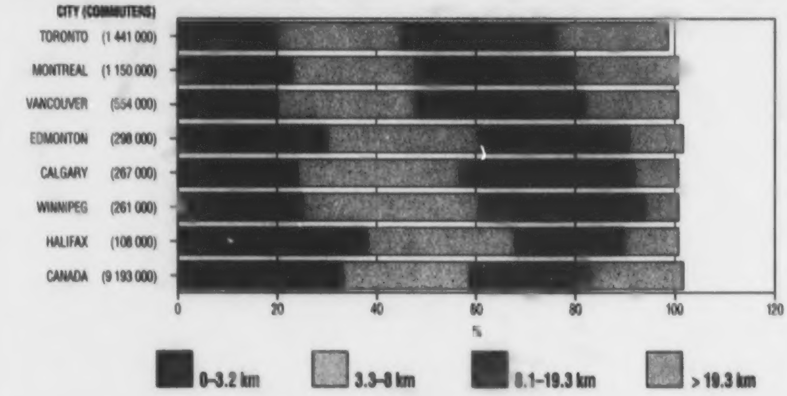
TOWARDS THE ENVIRONMENTALLY FRIENDLY CITY

Given the present state of the urban environment, the major issues that Canadian cities will have to face in the near and long term could be categorized as follows:

1. The transportation sector accounts for a major portion of urban energy use, air pollution, and greenhouse gases, and moving to more efficient intra-urban transit can result in significant progress on all of these fronts.
2. Solid waste is currently a high-profile issue for urban centres, given shrinking landfill sites and the unceasing flow of waste.
3. Urban water issues, including sewage treatment, industrial effluents, storm runoff, water quality, and consumption, have serious implications for human health and the quality of life in cities.
4. Although energy use is mainly relevant to the transportation sector, there is a great deal of opportunity for reducing consumption in buildings.
5. Green space and the conservation of natural areas are important for urban environmental quality in terms of aesthetics, natural ecosystem functions (e.g., wetlands filtering urban waterways), and preservation of important natural resources (e.g., agricultural, forest, and wildlife resources).
6. Indoor environmental quality is a more recent issue that may surge in importance as we gain more information on its implications.

FIGURE 13.13

Commuting distances: distribution of commuters by distance to work for selected urban centres, 1980

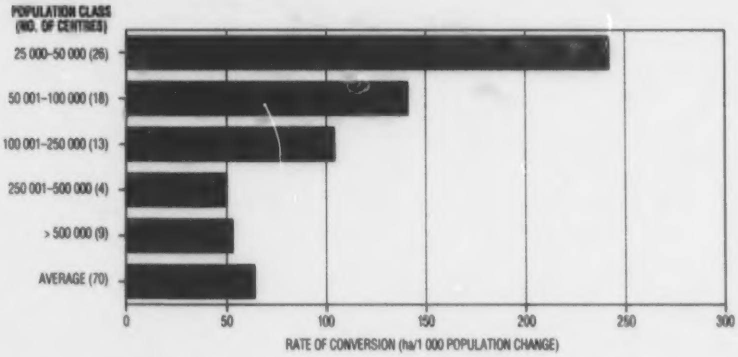


Note: Data are from a Statistics Canada survey carried out between 1976 and 1984.

Source: Statistics Canada (1982).

FIGURE 13.14

Urbanization of land: efficiency of land conversion by urban centre population size, 1981–86



Source: Warren *et al.* (1989).

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The state of the environment: a view from the city

How does the city perceive the national and global implications of environmental issues? It is tempting to assume that the city view is inward-looking, focusing on local high-profile issues such as drinking water quality, beach closings, and smog. Urbanites, however, increasingly recognize that the quality of life in a city and long-term sustainability are largely dependent on ecosystem health and the quality of the environment as a whole. Focusing on local issues will solve only half the problem if smog is still being produced downwind and sewage upstream.

This awareness is reflected in the strong public concern for environmental issues in urban areas (Statistics Canada 1991). Citizen groups and environmental nongovernment organizations assertively express their concerns over the health of local ecosystems and the biosphere as a whole, and city governments and planners are listening. So we find cities considering the promotion of efficient transit systems, not only as a response to the more immediate problems of smog and traffic congestion, but also as a contribution to the reduction of carbon dioxide emissions and global warming. There is also a greater awareness of hard-to-quantify values of the environment. Thus, the ecological functions, the aesthetic pleasures, and the educational values of protected natural areas in cities, for example, are being recognized.

Certainly, there are immediate concerns for urban dwellers. Water and air quality issues, for example, are very "close to home." These problems, however, can be traced to patterns of production, consumption, and waste that take place in cities themselves. The urban consumer is beginning to take responsibility as part of the problem and, potentially, part of the solution. This is shown in the growth of "green consumerism" and the high participation rates in municipal recycling programs.

The City of Ottawa's new draft official plan reflects this emerging holistic city view of environmental problems (City of Ottawa 1991). The concept of sustainable development is taken as an overriding principle in the plan. This concept is tailored to the dilemma of the city manager: balancing goals of economic development and prosperity, on the one hand, with the need to prevent and control environmental degradation and enhance environmental quality, on the other. The Ottawa approach is to attempt to link these two goals so that development is environmentally sensitive and environmental conservation supports appropriate development. The plan specifies environmental management strategies to be developed in consultation with nongovernment and community organizations. These strategies will include setting aside natural areas, energy conservation, air and water pollution control, and solid waste reduction. In other sections of the plan, environmental considerations are built in. For instance, guidelines in the transportation section are designed to reduce the reliance on the private automobile for intra-urban travel.

The city perspective on the state of the environment, then, is both inward-looking — concerned with enhancing the city's attractiveness to investors, for example — and outward-looking — including a concern for the health of the biosphere as a whole.

The tools available to cities to deal with environmental issues tend to be limited to land-use control (through bylaws and zoning) and the city's role in planning and building urban infrastructures (e.g., roadways, public transit, and sewer and water systems). In some instances, cities are required to implement policies of higher levels of government, which, depending on the situation, can encourage or inhibit effective management responses to environmental issues. The range of options is also dependent on the resources available, which can vary a great deal from city to city. Given the growing awareness and understanding of environmental issues coming from cities, their involvement in policy development at all levels could help to create national systems that support local responses.

Management responses to these urban environmental issues can include: adjustments in individual behaviours to conserve energy and materials; pricing and other incentives to encourage appropriate behaviours; new urban programs, such as solid waste recycling systems or expanded transit systems; new technologies and infrastructures, such as electricity-powered buses or tertiary sewage treatment plants, to deal directly with certain issues; and appropriate policy and land-use planning to set aside green space, conserve important natural resource areas, and support other environmental goals, such as efficient transit and energy conservation (see Box 13.3).

It is unlikely that these issues can be dealt with overnight, given the immense investment — in terms of capital, energy, and resources — in the present structures and infrastructures of the city. There is a great deal of inertia in the modern city's form, which has been inherited through an historical process governed largely by economics and demographics. A good understanding of this process and the major environmental issues, however, should be helpful to decision-makers in pinpointing where adjustments, planning guidance, and expensive redevelopment would be most effective: initiatives that result in the greatest environmental improvement work in tandem with existing social trends, which heavily influence city form.

The historical process of urbanization is continuing as two trends. First, a steadily increasing proportion of the Canadian population is concentrating in urban areas, themselves concentrated mainly in a relatively narrow belt across the country. Secondly, of the urban-dwellers, a growing proportion is accounted for by a small number of large metropolitan areas, which are spreading out in increasingly dispersed urban patterns and whose effects on land use extend even further. The distinction between these two trends — concentration on the national scale, deconcentration or dispersal on the regional and local scale — is of fundamental importance in environmental terms.

The clustering of people and their activities in urban areas does, in and of itself, have certain adverse effects on the environment. Clearly, a city is enormously destructive of natural ecosystems (although the same can be said of extensive agriculture, on a much larger scale). Runoff from the city's hard surfaces and contaminated snow removed from its streets in winter can contribute substantially to the pollution of the river or lake that receives it.

However, cities are often condemned by environmentalists for attributes that are actually those of the populations and economic activities they accommodate, rather than of the city itself. Air pollution, for example, is more noticeable and may be locally more harmful to health if its sources are concentrated in an urban area than if they are geographically dispersed, but dispersion will not by itself lessen the total volume of pollutants emitted into the atmosphere (although it may reduce the production of secondary pollutants, such as ground-level ozone). A water-polluting industrial plant will not be less of a polluter on a rural site than on an urban one, and its discharges may be more easily controlled and treated in a city.

Urban concentration actually has positive environmental values. It encourages medium- and high-density housing and supports transit use. It provides economies of scale for waste management and sewage treatment. Also, a recent survey suggests that city-dwellers are more inclined than rural people to be sympathetic to environmental concerns (Statistics Canada 1991). On balance, cities may well make good environmental sense; at least, it is far from clear that they do not.

Furthermore, intelligent urban planning and enlightened use of technology can do a great deal not only to mitigate the undesirable environmental characteristics of the city, but to enhance greatly the positive elements (see Box 13.4). Energy conservation and the use of public transit, bicycle, and foot travel can be promoted by multiple use of land and suitable residential densities. Savings in land, energy, and municipal services can be made by rehabilitating

The green city of the future

A city in harmony with nature is still a futuristic vision, but it is not a pipe dream. Everything necessary to create these cities of the future is now within our capabilities; most of the concepts have been tested in Canada or elsewhere. Let us envisage what a truly environmentally planned city might look like a few decades from now.

Ecosystem planning

The environmentally planned city bases its development on a long-range plan for growth and change. City planners fully understand the regional ecosystem into which the city fits and evaluate all significant physical change in relation to ecological processes and linkages (Royal Commission on the Future of the Toronto Waterfront 1989).

Natural watercourses, water bodies, and wetlands are preserved and, where necessary, restored to an approximation of their original condition. The expanded wetland areas help conserve water and purify city sewage, and they provide excellent wildlife habitat.

These wetlands, together with woodlands, have altered the very nature of the urban environment. Swaths of green penetrate from the outskirts of the city to its centre, providing many kilometres of shaded nature walks and cycle paths along rivers and creeks, with here and there a garden area and space for games and playgrounds. Like the wetlands, the forest areas offer the city-dweller opportunities for recreation and education, while filling other highly useful functions: they provide shade and visual relief, and they help maintain the city's air quality. Natural woodlands are protected, and new woodlands have been planted on abandoned land throughout the urban area and on other public and private land, where space permits. The network of trees — most of which are indigenous species — is managed as an urban forest, even serving as a commercial source of high-value timber.

To keep the city in balance with the ecosystem and preserve the productive agricultural land that surrounds it, a firm boundary has been drawn around the urban area. The boundary is extended only rarely and in circumstances of clear necessity. As a result, the outermost buildings of the city abut thriving farms.

Housing in the green

In the central city, housing is compact, although there are relatively few high residential buildings. The prevalent housing form consists of rows or groups of two- or three-storey buildings, surmounted by solar panels and containing a variety of sizes of unit and types of occupancy. Despite the compactness of the residential districts, every household has a small area of open space for its private use, perhaps on a roof. The large expanses of green throughout the city keep its overall population density only slightly higher than that of the old-fashioned single-family suburbs.

From any dwelling, it is no more than a few minutes' walk to a sheltered transit stop with lockable bicycle storage: these are generally adjacent to a local shopping mall or community centre. Nearby, wooded trails eventually lead walkers and cyclists either close to the city centre or out to the countryside. Most people do not own cars, because they are much less convenient to use within the city than is public transportation, and because they are inconvenient and expensive to store or park when not in use.

Most of the asphalt surface of older residential streets has been replaced by trees, benches, and playground equipment. The remaining paved stretches are narrow and irregular, designed to discourage vehicles other than bicycles, emergency vehicles, and

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the electricity-powered vehicles that collect the garbage. To reduce waste, garbage has been sorted and stored for reuse and recycling. If there is absolutely no alternative, the waste is transported to a landfill site, but the appropriate charge must be paid.

Working environments

Commercial building density in the central business district is still high, as it has been for decades. This is now managed through careful three-dimensional urban design, including vertical separation of different forms of movement and activity and the virtual exclusion of private vehicles. Workers and residents of the central business district can move about and relax in a vehicle-free system of linked open spaces laced with pools and fountains — some completely urban in character, others well-treed parks.

With the decline of heavy industry, the city has shifted to a new economic base whose environmental impacts are comparatively slight, consisting mainly of truck traffic. Employment areas can therefore be interspersed among the residential districts, within easy reach of workers by transit or even on foot, instead of being segregated into remote locations.

Satellite communities

Although peripheral expansion of the city is not acceptable, growth is inevitable and indeed welcome. High-speed trains link the city centre to a number of urban satellites, their sites carefully chosen and planned according to the same principles as the central city. Some of these are located many kilometres away, in agriculturally unproductive regions once in economic decline. However, by taking advantage of the changing economy, the satellites have built their own economic bases. And because the satellites rely on electronic linkages, the volume of daily travel between the satellite communities and the central city is usually fairly low.

The city view of an airline passenger is of a well-defined pattern: much of the urban region is made up of well-defined patches distributed into rural areas far beyond the central city, which in turn is penetrated to its core by green strips and wedges. City and countryside intermingle, but in an orderly, planned symbiosis instead of a haphazard, destructive diffusion of one into the other.

It can be done.

old buildings and neighbourhoods. A variety of environmentally positive features can be designed into redevelopment projects, such as green space, bicycle storage, and proper provision for the storage and collection of waste materials for reuse and recycling. Green areas, including remnant wilderness areas, can be preserved, linked, and supplemented by extensive tree-planting on public lands, private sites, and even buildings.

Much can also be done to enhance the environmental quality of new urban areas on the edge of the city. Residential developments can be planned and individual buildings can be oriented and designed to make the fullest use of the land they occupy, to minimize total street area, to take advantage of gravity for piped services, to take maximum advantage of sunlight, and to preserve woodlands, stream valleys, and other features of the natural landscape (Lang and Armour 1982). Cycle and footpath systems linked to transit routes can be provided. Environmentally sensitive landscape design can go far to offset lost natural environmental values, as well as enhancing property values. Suitable construction standards, such as high insulation values and provision for passive solar heating, can conserve energy. Perhaps most important of all, densities can be substantially increased by using smaller lots and zero lot lines (permitting building to the street) and by including alternatives to the single detached house, such as row or "stacked" condominium and cooperative housing with private exterior space and individual-unit facades, that retain the key values of ownership, investment opportunity, identity, and indoor and outdoor privacy.

All of these measures, and others, have been put into practice in various Canadian communities, but they require creativity and innovation in planning policies, implementation mechanisms, and standards. They may also require trade-offs to be made. For example, conservation of land on the edge of the city has to be balanced with the provision of affordable housing; energy efficiency in residential planning and design with the provision of space and privacy; transit-oriented urban intensification with the separation of incompatible land uses; optimal use of centrally located land with the preservation of green space; the merits of rehabilitation (such as savings in materials and energy) against those of redevelopment (such as more intensive use of land). Effective environmentally oriented planning therefore calls for the cooperative efforts of all levels of government, the private sector, and the public. At present, the chief obstacle is not lack of technical knowledge and experience, but obeisance to the "rights" of land ownership and widespread reluctance on the part of consumers, land developers and builders, and municipal councils to accept new approaches to urban land use and "new" forms of housing.

If nationwide urban concentration is not necessarily environmental bad news, localized and regional deconcentration is another matter. In its present form, the evolving regional pattern of urbanization, or quasi-urbanization, has little positive to set against its very serious environmental failings. It is wasteful of land and crippling to agriculture far beyond the edge of the city. It brings about unnecessary destruction of woodlands, wetlands, and other areas and features of ecological, scenic, and recreational value. It can create hydrological problems, affecting water supply, water quality, and aquatic habitat. It places heavy demands on energy supplies, construction aggregates, and other resources needed to service it. And its dependence on the automobile greatly increases private vehicle use not just within the fringe areas, but throughout the urban area as well, leading to additional resource demands as well as air and noise pollution.

However, demographic and economic trends, in combination with modern information, communications, and transportation technology, ensure that regional deconcentration is going to continue for the foreseeable future. It should not be necessary to view this prospect with alarm; from an environmental standpoint (as well as others), the dangers and problems lie not in deconcentration as such, but in the way it takes place. The haphazard "sprawl" pattern that has typified the outskirts of Canadian cities for the past four decades does not have to continue indefinitely. Through effective planning on a genuinely regional scale, future growth could be organized around the expansion of existing towns and the creation of new urban subcentres, located, where possible, on land of poor agricultural quality, compactly built, and linked to the central city by efficient public transportation. "Urban envelopes" could be tightly drawn, clearly defined, and firmly enforced, guaranteeing the long-term rural character of the surrounding areas and safeguarding areas of ecological, hydrological, and scenic importance. The prescription is, in fact, well known and has long been employed in other countries. The issue in Canada is one of public acceptance.

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14

HIGHLIGHTS

During the last 20–30 years, some forms of pollution from manufacturing and primary processing industries have declined.

■

Industrial processes remain the principal source of such pollutants as sulphur dioxide, suspended particulates, and CFCs. However, industrial emissions of sulphur dioxide (the primary source of acid precipitation) were cut by nearly half between 1970 and 1985 and are targeted to reach half the 1980 level by 1994. Similarly, emissions of total particulate matter from industrial plants declined by nearly 36% between 1970 and 1985. Production of CFCs (linked to the destruction of the ozone layer) is to be phased out completely by the year 2000.

■

Fuel use for power, heating, and transportation accounts for 90% of carbon dioxide emissions.

■

Data from individual industrial sectors indicate a significant improvement during the 1970s and 1980s in many indices of water pollution, including suspended solids, oxygen-demanding material, persistent and nonpersistent toxic chemicals, and nutrients. However, allowable discharge limits of various pollutants have been exceeded by some facilities. A study of 170 industrial plants in Ontario reported that 54% regularly exceeded their monthly pollution limits in 1989.

■

Industry has been far less successful in controlling its output of hazardous wastes. In 1986, Canadians produced an estimated 8 million tonnes of hazardous wastes, the vast majority of which came from industrial sources. It is estimated that as many as 1 000 sites in Canada are contaminated by hazardous wastes.

■

Although about half of the hazardous wastes generated in Canada have recycling potential, only a small proportion of these wastes are as yet being reclaimed. Waste exchanges have been set up in several provinces to encourage the recycling and reuse of these materials.

■

Because much industrial demand is consumer driven, efforts to reduce pollution must focus not only on the cleaning up of industrial processes themselves but also on the modification of consumer demands and practices.

■

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> **It was a town of machinery and tall chimneys, out of which interminable serpents of smoke trailed themselves for ever and ever, and never got uncoiled. It had a black canal in it, and a river that ran purple with ill-smelling dye, and vast piles of building full of windows where there was a rattling and a trembling all day long, and where the piston of the steam-engine worked monotonously up and down, like the head of an elephant in a state of melancholy madness.**
>
> — Charles Dickens (1854)

INTRODUCTION

Leaden clouds of sinister black smoke belching up into the clear air from towering factory chimneys are an instantly recognized image of pollution. Yet a picture of many woodsmoke plumes drifting lazily into the evening sky from residential fireplaces seldom elicits the same recognition. These very different interpretations of pictures of air pollution indicate how polluting emissions have come to be identified primarily and almost exclusively with industrial activities.

Historically, there are very good reasons for this close linkage between industries and pollution. For many years, industrial emissions were largely uncontrolled, and factories were foul, smoke-spewing places that turned the landscapes around them into wastelands of devastation. Industrial plants, although not the only polluters, were certainly the most visible polluters in industrialized countries for all of the 19th and most of the 20th centuries. Even today, the birthplace of the industrial revolution in the midlands of England is referred to as the black country.

The popular view of industrial factories as polluters is also based on a recognition of the extraordinary power of industries to alter the environment. By combining new technology, new forms of energy, and new modes of economic and social organization, the industrial revolution brought about an exponential increase in human productivity. With this came a corresponding increase in the power of human beings to consume natural resources and to release prodigious quantities of noxious products and by-products into the environment. The industrial revolution marked a turning point in humanity's ability to alter its environment.

Pollution cannot continue to be perceived as an exclusively industrial problem. Although industrial manufacturing sites have been readily identified as large potential sources (i.e., stationary point sources) of concentrated polluting emissions, they are also among the most amenable to emission control and reduction. Consequently, in the last 20–30 years, important steps have been taken to bring the industrial impact on the environment under control. At the same time, other sectors of society have emerged as significant polluters. As a result, the role of industries in environmental problems and their place in the hierarchy of polluters have begun to change significantly.

In this chapter, the term industries covers primary resource extraction such as mining, primary processing activities such as pulp and paper manufacturing and petroleum refining, and secondary processing and manufacturing endeavours such as petrochemicals (e.g., styrene monomer, polyester fibre) and final products manufacturing (e.g., clothing, automobiles). The objective is to provide a better perspective on the significance of many very diverse industrial plant site activities to current environmental problems.

AIR POLLUTION

Types of air pollutants, and their effects

Every day, human activities emit millions of tonnes of polluting material into the atmosphere. Gases such as nitrogen oxides, carbon monoxide, and carbon dioxide — mostly from the burning of fossil fuels — account for a large part of this material. Dust, soot, and a variety of other particles, most of them microscopic in size, are another significant component, as are vapours and aerosols from the thousands of different chemicals that we use routinely in our factories and homes.

Some pollutants interact to produce other pollutants. Gasoline, dry-cleaning solvents, and many other chemical products, for example, contain volatile organic compounds (VOCs) whose vapours react with oxides of nitrogen in the presence of sunlight to produce ozone in the lower atmosphere and contribute to smog formation. Under the right conditions, ozone concentrations at ground level can build up to harmful levels.

Many pollutants pose a serious threat to health. Occasionally they can kill, as they did in London, England, in December 1952, when a four-day smog left some 4 000 people dead. Air pollutants primarily affect the respiratory system, with sulphur dioxide, nitrogen dioxide, ozone, and particulate matter being the most common irritants. Epidemiological studies have linked these pollutants to impaired lung function, increased susceptibility to respiratory infection, and the worsening of existing respiratory conditions such as asthma and bronchitis (National Research Council 1985).

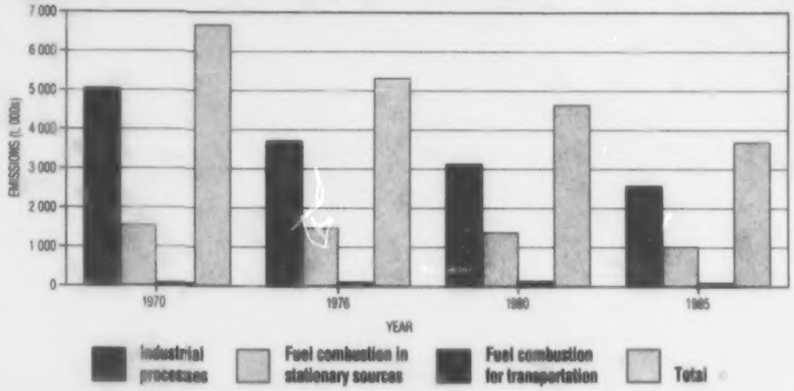
Other pollutants have been associated with a variety of nonrespiratory effects. Carbon monoxide, for example, can affect mental and motor capacity at levels that are sometimes found in polluted city air. In addition, a number of highly toxic substances can be present in the air, often bonded to very fine particles that are easily inhaled and that lodge deeply within the lungs. The effects of these contaminants vary, but some, such as lead, can damage the central nervous system and other organs, whereas others, such as some polycyclic aromatic hydrocarbons (PAHs), can cause or promote cancer.

Many air pollutants have harmful effects on other living things in the environment. Plants, both domesticated and wild, show a variety of effects in polluted air, including a slower rate of photosynthesis, changes in enzyme activity, loss of foliage, and reductions in growth and seed production. Air pollution, in concert with climatic change and other environmental stresses, is thought to be a critical factor in the dieback of forests (Hilborn and Still 1990).

Air pollutants are also significantly altering important aspects of the chemical and physical composition of the environment. Human emissions of sulphur and nitrogen dioxides are the principal cause of acid precipitation, which has left hundreds of lakes and rivers in Europe and North America seriously degraded (see Chapter 24). Synthetic chemicals such as chlorofluorocarbons (CFCs) and halons are playing a key role in the depletion of the stratospheric ozone layer (see Chapter 23), whereas carbon dioxide, CFCs, methane, and nitrous oxide are altering the heat-regulating capacity of the atmosphere and possibly inducing an unprecedented change in the world's climate (see Chapter 22).

FIGURE 14.1

Sulphur dioxide emissions in Canada, 1970–85



Source: Environment Canada

The industrial contribution to air pollution

Industrial processes can release many of these pollutants to the atmosphere through smokestack emissions, equipment leakage, accidental releases, and the evaporation of volatile chemicals. Numerous other human activities pollute the atmosphere as well: transportation, agriculture, electric power generation, commercial and residential heating, the burning of waste in incinerators, land clearing, and construction all contribute to atmospheric pollution. Given such a wide variety of polluting sources, how significant is the industrial contribution to current air pollution problems?

As Figure 14.1 shows, sulphur dioxide emissions fell by almost 45% between 1970 and 1985. Industrial processes were, and remain, the largest source of sulphur dioxide releases in Canada, mainly because of the contributions from metal production and petroleum recovery and processing, which accounted for 90% of industrial releases in 1985 (Table 14.1). However, almost all of the improvement in sulphur dioxide releases can be accounted for by decreases in industrial emissions, which fell by nearly half during the 1970–85 period. By 1994, sulphur dioxide emissions are projected to be only half of the 1980 output.

Similarly, industrial plant emissions of total particulate matter declined by about 36% between 1970 and 1985; however, total emissions decreased by only 16% due mainly to an increase in emissions from transportation (Fig. 14.2).

Emissions of nitrogen oxides, on the other hand, rose by more than 40% between 1970 and 1985 (Fig. 14.3). The majority of nitrogen oxide emissions (over 60%) come from the transportation sector, principally from motor vehicles. Fuel use in homes, businesses, and power plants contributes another 30% (Table 14.1). Between 1970 and 1985, the number of cars and trucks on the road increased by about 70%, and this, more than any other single factor, has been responsible for the rise in nitrogen oxide releases.

TABLE 14.1

Summary of national emissions of air pollutants, 1985

	Emissions (t)						
Category	**Total particulate matter**	**Sulphur dioxide**	**Nitrogen oxides**	**Carbon monoxide**	**Total hydrocarbons**	**Volatile organic compounds**	**Carbon dioxide (1987)**
Industrial processes:							
Crude oil		30 003			27 311	15 021	
Iron ore	90 800	114 733	1 320	47 518	83	33	
Iron & steel	26 976	15 701	5 898	216 587	6 129	5 428	
Aluminum	21 449	25 244	3 583	226 952	4 457	4 456	
Copper & nickel	23 648	1 629 458	5 153	3	15	13	
Lead & zinc	4 405	120 289	209	17	1	1	
Oil refineries	5 886	49 268	10 504	62 140	67 858	40 300	
Gas plants	724	264 198	19 619		9 073	1 988	
Coal industry	166 522	1 026	1 316	49	261 542	2	
Petrochemicals	8 148	6 837	8 394	12 642	42 775	36 400	
Plastics					13 700	13 700	
Kraft pulping	112 865	27 734	19 991	61 521	9 134	9 134	
Tar sands	1 851	106 007	5 183	5 256			
Asbestos	4 167	6	5	1			
Mining & rock quarrying	201 851	13 830	171	70	5	5	
Carbon black	122	2 703	2 852	117 211	7 213	6 131	
Chemical pulping	2 163	32 591	130				
Sawmills	77 838	35	644	9 758	1 023	1 023	
Other	305 035	51 543	22 569	67 484	24 543	24 490	10 330 358
Subtotal	1 054 449	2 491 206	107 541	827 209	474 862	158 124	10 330 358
Fuel combustion:							
Stationary							
Refineries	4 343	67 270	20 907	52 884	1 827	1 053	
Gas plants	362	1 497	138 947	25 892	43 075	4 436	23 336 510
Other industrial	99 939	239 631	97 684	476 184	56 990	50 078	106 316 099
Total industrial	104 644	308 398	257 538	554 960	101 892	55 567	129 652 609
Commercial	2 714	23 612	25 926	6 962	2 077	1 332	21 146 105
Residential	4 568	31 798	37 562	16 450	5 272	2 664	41 993 640
Fuelwood	155 919	3 746	3 899	624 212	108 023	107 866	9 157 866
Power plants							
Utilities	266 713	735 653	234 504	55 943	3 389	2 927	94 440 158
Other	890	1 792	12 831	3 220	923	10	
Total power plants	267 603	737 445	247 335	59 163	4 312	2 937	94 440 158
Subtotal	535 448	1 104 999	572 260	1 261 747	221 576	170 367	296 390 378
Transportation:							
Gasoline							
Cars	43 256	10 622	352 000	4 015 545	458 556	412 700	48 351 409
Light-duty trucks	9 740	3 996	95 400	1 416 139	158 556	142 700	20 444 931
Heavy-duty trucks	2 549	750	20 900	335 208	27 889	25 100	5 306 318
Motorcycles	249	32	968	14 841	4 851	4 366	215 522
Total gasoline	55 794	15 400	469 268	5 781 733	649 851	584 866	74 318 180

TABLE 14.1 (CONT'D)

Category	Emissions (t)						
	Total particulate matter	Sulphur dioxide	Nitrogen oxides	Carbon monoxide	Total hydrocarbons	Volatile organic compounds	Carbon dioxide (1987)
Diesel							
Light-duty trucks	1 265	1 794	5 700	3 426	1 548	1 393	2 161 009
Heavy-duty trucks	14 848	19 600	264 300	100 348	31 889	28 700	19 405 971
Other	20 487	14 867	230 304	69 559	25 967	23 370	14 092 220
Total diesel	36 600	36 261	500 304	173 333	59 403	53 463	35 659 200
Total road vehicles	92 394	51 661	969 572	5 955 066	709 255	638 329	109 977 380
Railroads	6 634	7 077	132 100	49 066	6 216	5 968	5 396 163
Marine	3 569	33 361	16 747	84 898	30 589	27 922	5 219 354
Aircraft	1 063	1 732	33 499	116 551	11 412	10 157	12 271 756
Off-road gas	2 489	921	28 169	958 838	66 792	66 113	3 964 459
Tire wear	33 566				673	673	
Propane							1 385 416
Subtotal	139 715	94 752	1 180 087	7 164 419	824 937	749 162	138 214 528
Incineration:							
Wood waste	34 423	321	3 207	416 924	35 465	7 226	8 957 212
Other	3 410	1 436	2 477	10 715	30 109	6 020	1 322 171
Subtotal	37 833	1 757	5 684	427 639	65 574	13 246	10 279 383
Miscellaneous:							
Fuel marketing					108 799	108 770	
Structural fires	6 262			12 524	6 262	6 262	
Pesticides application	9 543						
Slash burning	219 614		19 819	1 134 496	126 412	96 416	15 712 254
Other	12 539			1 880			
Solvent use							
Dry cleaning	5	74	36	1	14 000	14 000	
Surface coatings	4				187 500	187 500	
General use					300 500	300 500	
Total solvent use	9	74	36	1	502 000	502 000	
Subtotal	247 968	74	19 855	1 148 901	743 473	713 448	15 712 254
Total	**2 015 412**	**3 692 788**	**1 885 428**	**10 829 914**	**2 330 422**	**1 884 347**	**470 926 901**

Source: Environment Canada.

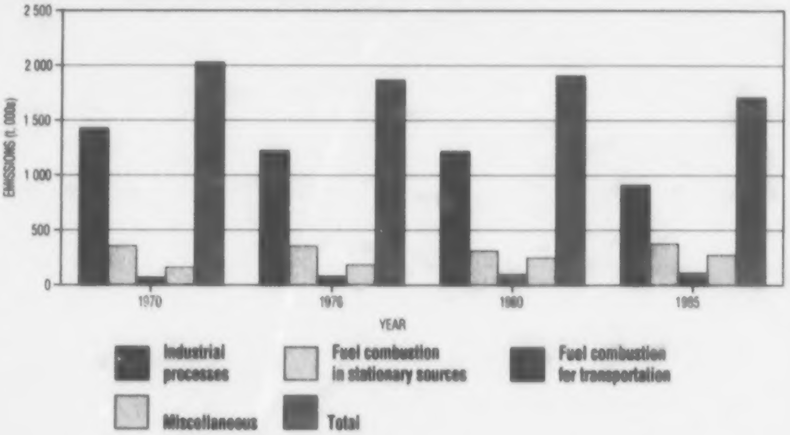
Carbon monoxide emissions have increased only slightly since 1970 (Fig. 14.4). The breakdown of sources shows a pattern similar to that for nitrogen oxides: transportation contributed 66% of releases in 1985, whereas industrial releases amounted to less than 8% of the total (Table 14.1).

Ground-level ozone levels declined during the early 1980s but showed an upturn towards the end of the decade. The extent of ozone pollution is determined by weather conditions and by the presence of precursor pollutants — primarily nitrogen oxides and VOCs. The industrial contribution to ozone formation in the ozone problem areas is only about 20% of the total (Canadian Council of Ministers of the Environment 1990).

Although the petroleum, petrochemical, and coal and coke industries emit substantial amounts of hydrocarbons, including such carcinogenic varieties as benzene and PAHs, the total industrial output of hydrocarbons amounts to about 60% of that from transportation sources (Table 14.1). However, although some improvement has been seen in transportation emissions, this has been more than offset by increases from industrial sources. Between 1970 and 1985, the industrial share of hydrocarbon emissions rose by 60%, compared with a decline of about 20% in the transportation share (Fig. 14.5).

FIGURE 14.2

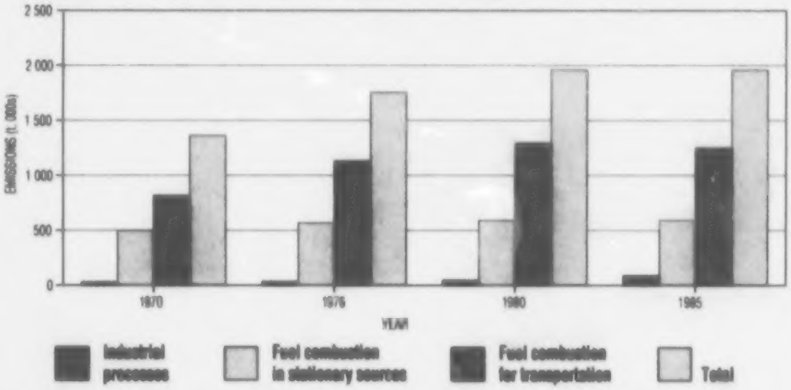
Particulate matter emissions in Canada, 1970–85



Source: Environment Canada.

FIGURE 14.3

Oxides of nitrogen emissions in Canada, 1970–85



Source: Environment Canada.

Until recently, the use of lead additives in gasoline accounted for approximately two-thirds of the lead entering the atmosphere. With the phasing out of these additives, the industrial contribution (primarily from the production of lead, zinc, copper, and nickel) has now become the main source of lead emissions to the air (Fig. 14.6). Lead smelters and reclaimers can be significant contributors of lead to local environments. Lead is persistent in the environment and in some problem areas has reached levels that have posed a hazard to human health and required the taking of remedial steps, such as soil removal (Stokes 1986).

Some industrial sectors have contributed substantially to the depletion of the ozone layer through their use of CFCs and other ozone-depleting chemicals. In 1989, 44% of the CFCs consumed in Canada were used in industrial and domestic refrigerators and air conditioning systems, 39% were used as foam-blowing agents, and another 12% were used as industrial solvents (Fig. 14.7). Industries have also been the major users of other ozone-depleting chemicals, such as carbon tetrachloride and methyl chloroform. Under the Montreal Protocol on Substances that Deplete the Ozone Layer of 1987, Canada will phase out the production and use of five types of CFCs by 1997. Canada is also committed to phasing out uses of other CFCs, halons, carbon tetrachloride, and methyl chloroform by the year 2000.

The principal greenhouse gases are carbon dioxide, CFCs, methane, ozone, and nitrous oxide. Carbon dioxide accounts for most of the increase in global warming, and atmospheric concentrations have been rising globally by about 0.5% a year. In 1987, industries accounted for about 30% of Canada's carbon dioxide releases, roughly the same percentage as from the transportation sector (Table 14.1) (see Chapter 22).

Some industrial sectors use a great variety of chemicals in their operations, but to date there are only limited data available on the emissions of these chemicals.

Controlling air pollution

In the last two decades, considerable progress has been made in reducing and controlling industrial emissions of air pollutants. In many cases in which industries have been the major sources of pollutants, emissions have been reduced substantially (most notably those of sulphur dioxide) or the production of the offending substance has been phased out (as is now happening with CFCs and other ozone-depleting chemicals).

This is not to say, however, that industries are no longer significant sources of all air pollutants. Individual industrial facilities can still be substantial sources of pollution that can cause local environmental damage or health problems. Also, there are areas in which further improvements must be made. The continuing increase in global emissions of carbon dioxide will soon have to be halted if the dangers of rapid global warming are to be lessened. This will inevitably require a significant reduction in industrial carbon dioxide emissions. Also, as has been stated above, there are many other air pollutants that are not routinely monitored, so very little can be said about progress made in controlling their emissions.

Nevertheless, some of the most urgent air quality problems of the next decade involve pollutants that originate primarily with fuel use. These are nitrogen oxides and VOCs, the gases primarily responsible for photochemical smog, and carbon dioxide, the major greenhouse gas. The growing number of cars and trucks on the road and the energy intensity of our industries and lifestyles mean that more strenuous steps are required to bring releases of energy-related pollutants under control.

WATER POLLUTION

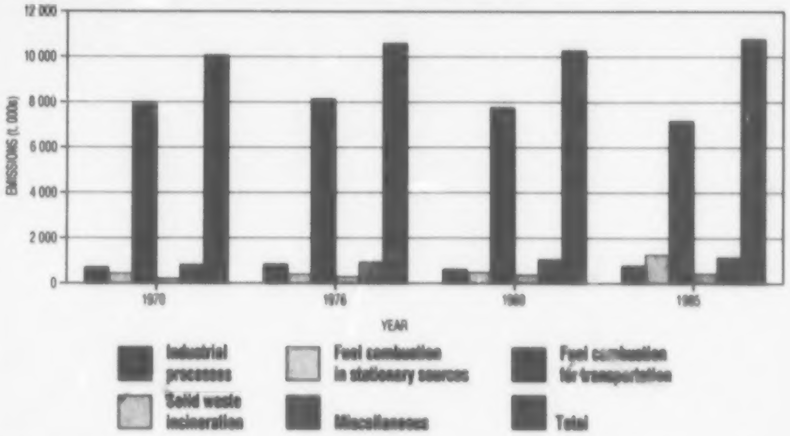
Sources of water pollution

A substantial portion of the wastes entering our water comes from point sources such as industrial discharge pipes and municipal sewer outlets. Industries that discharge their wastes directly into a water body are regulated by federal and provincial laws. In order to meet the requirements of these regulations, their effluents normally undergo some form of treatment before being released. However, this treatment is not always adequate. A recently released study of 170 direct dischargers in Ontario reported that 54% regularly exceeded their monthly pollution limits (Ontario Ministry of the Environment 1991). The design of an industrial waste treatment facility depends on the pollutants it is required to treat. The food processing industry, for example, produces wastewaters that are high in biochemical oxygen demand and total suspended solids and therefore require biological removal and settling. A metal finishing operation, on the other hand, releases metal residues and cyanide, which require chemical treatment for removal.

Municipal wastes may contain a considerable quantity of industrial effluent. In fact, most industries, particularly smaller ones, discharge their wastes into municipal sewers. Local bylaws may limit the substances that can be released into the sewers and may require pretreatment of some wastes, but generally the object of these bylaws is to protect the sewage system against upsets rather than to control the release of environmentally harmful materials. Municipal sewage may receive as many as three levels of treatment

FIGURE 14.7

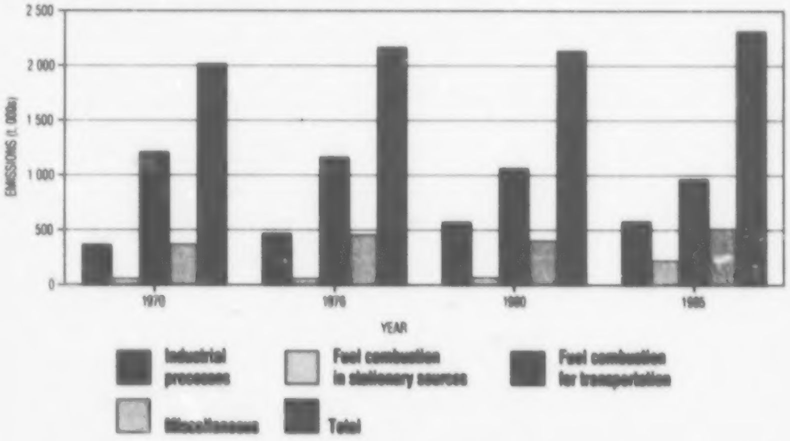
Carbon monoxide emissions in Canada, 1970–85



Source: Environment Canada.

FIGURE 14.8

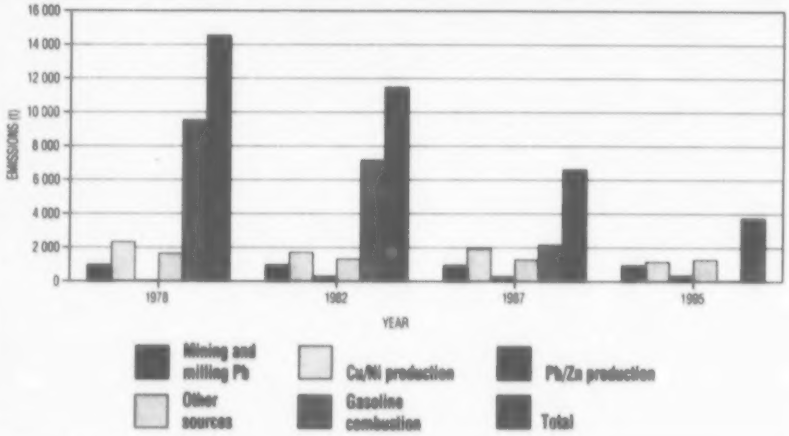
Hydrocarbon emissions in Canada, 1970–85



Source: Environment Canada.

FIGURE 14.6

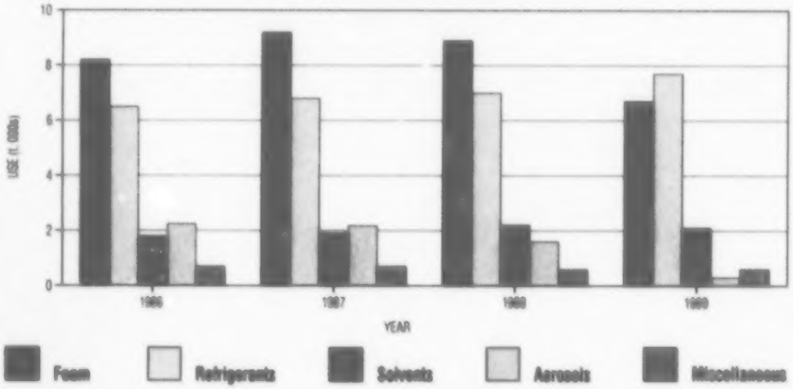
Distribution of lead emissions in Canada, 1978–95



Source: Hilborn and Still (1990).

FIGURE 14.7

Chlorofluorocarbon use in Canada, 1986–88



Source: Environment Canada.

(see Box 14.1), or it may receive no treatment at all: many towns and cities continue to discharge raw sewage into open waterways. Municipal sewage systems therefore cannot always adequately treat the toxic chemicals found in some industrial effluents, nor can municipal authorities adequately police what is disposed of in their sewers. As a result, even treated sewage may contain significant quantities of toxic material.

The air is also a major source of contaminants for many water bodies, particularly those, like the Great Lakes, that have large surface areas. Persistent pollutants can be carried long distances by prevailing winds, contaminating open waters far from the pollution source. Runoff from cities adds biological wastes, as well as traces of virtually every chemical used in the urban environment, to the pollution load; agricultural runoff contributes agricultural chemicals such as pesticides, along with manure and fertilizer residues. In addition, water is commonly polluted by seepage from landfill, overflows from sewer systems, leaks, spills, and illicit dumping from industrial sources, and discharges from boats and ships.

Types of water pollutants

The principal substances affecting water quality are suspended solids, biochemical oxygen demanding material, toxic contaminants, and nutrients.

Total suspended solids

Suspended solids are solid particles that are fine enough to be transported by a fluid. These settle on river or lake bottoms and can upset aquatic habitats, disrupting fish and plant life and ruining spawning beds. Toxic chemicals may also adhere to the surfaces of these particles. The food processing, pulp and paper, and ore processing industries all generate large quantities of suspended solids. Other common sources include domestic sewage, eroded silts and soils, and airborne particles.

Biochemical oxygen demanding material

Many effluents, such as those from sewage systems, pulp mills, and food processing plants, contain high levels of organic wastes. As this material is broken down by microorganisms in the water, oxygen is consumed. The rate of oxygen consumption depends on the nature and quantity of the organic matter and the volume and turbulence of the water. If the rate of consumption is excessive, the oxygen content of the water will be depleted, and fish and other aquatic life may die.

Biochemical oxygen demand (BOD) is a common measure of the oxygen-depleting potential of these organic contaminants. Some inorganic chemicals also consume oxygen when they break down. A related measure, chemical oxygen demand (COD), is used to predict the effect of these chemicals on a water body.

The pulp and paper industry is a large producer of biochemical oxygen demanding material. The average

BOD of pulp mill effluent in 1985 was 354 mg/L. Because fish require oxygen concentrations of 5–6 mg/L to survive, effluent of this concentration must be diluted considerably to avoid risks to fish populations. In the past decade, the pulp and paper industry has reduced both the volume of its effluent and its BOD. In 1978, Canada's 122 direct discharge mills discharged an estimated 8 809 000 m^3 of effluent per day with a total BOD of about 3 000 t. In 1985, discharges were down to 5 801 000 m^3 of effluent per day with a BOD of about 2 000 t (see Fig. 14.14).

BOX 14.1

Treating liquid municipal wastes

Most, although by no means all, communities in Canada operate some form of sewage treatment system. Depending on their sophistication, these may provide as many as three levels of treatment. Primary treatment involves the settling and removal of solids only. Secondary treatment is designed to reduce biochemical oxygen demand (BOD). This is accomplished by aerating the wastes to encourage the growth of microorganisms that convert organic matter into carbon dioxide and sludge. Tertiary treatment removes certain dissolved chemicals, such as phosphorus, as well as additional solids. The chemical, mechanical, and biological processes used depend on the chemicals to be removed.

Most systems are designed to reduce BOD, total suspended solids (TSS), and phosphorus to acceptable levels before the effluent is discharged to an open waterway. For very sensitive receiving waters, ammonia and nitrogen compounds may also be removed.

Toxic contaminants

The largest volume of toxic pollutants consists of nonpersistent materials, such as oil and grease, phenols, ammonia, acids, and sulphur compounds, that break down after a short period of time into less harmful by-products. Also of concern are toxic substances that are highly persistent and readily absorbed by living tissue. These chemicals accumulate in the food chain and can cause organ damage, birth defects, cancer, and other serious health problems in wildlife and humans. The chemicals most seriously implicated in these problems fall into three groups: heavy metals, such as lead and mercury; chlorinated organic compounds, such as PCBs, dioxins, and furans; and hydrocarbons, such as some PAHs (see Chapters 3, 16, 18, and 21).

Nutrients

Phosphorus and potassium are essential for plant production in aquatic ecosystems. However, an oversupply of these nutrients can stimulate excessive plant growth, a process known as eutrophication (see Chapters 3 and 4). Algae multiply rapidly in eutrophic waters, and, when they die, their decomposition depletes the water's oxygen content and results in the death of fish, plants, and other aquatic life.

Although these nutrients are present in a variety of industrial effluents, agricultural runoff, which contains residues of chemical fertilizers and manure, and municipal sewage contribute a substantial portion of nutrient loadings. Until the early 1970s, laundry detergents containing phosphates were probably the largest single source of nutrient pollutants and played a major role in the eutrophication of Lake Erie in the 1960s. Phosphate discharges have largely been brought under control by reductions in the phosphate content of detergents and the introduction of treatments to remove them from municipal effluents.

The industrial contribution to water pollution

Although information on discharges of water pollutants from specific facilities is often more detailed than information on air emissions, it is difficult to make quantitative comparisons between industrial discharges of water pollutants and water pollutants from other sources. However, it is clear that, although industrial facilities can be major sources of water pollution, their collective contribution is not disproportionately greater than that of other sources. Household sewage, agriculture, and transportation have also had serious effects on water quality. Moreover, many industrial sectors have improved their records with respect to water pollution in the last two decades, with total discharges of suspended solids, BOD, monitored toxics, nutrients, and most other pollutants generally being far lower than those recorded in the early 1970s. However, as recent Ontario documentation shows, the general improvement of the industrial record masks inconsistencies in pollution control efforts at the level of individual companies and facilities. Whereas some companies have made great strides in pollution control, many still fall short of current emission standards (Ontario Ministry of the Environment 1991). As a result, pollution "hot spots" continue to exist in the vicinity of some industrial outlets (see Chapters 16 and 18).

HAZARDOUS WASTES

Hazardous wastes are those that pose a risk to human health or the environment and require special disposal techniques to make them harmless or less dangerous. Common examples of hazardous wastes include acids from metallurgical processes, spent caustic from pulp and paper operations, and residues from oil refining. These substances contain an enormous variety of dangerous chemicals, including phenols, arsenic, lead, mercury, and PAHs. Some wastes contain highly persistent toxic chemicals, such as PCBs, dioxins, and furans, that remain in the environment for very long periods of time and are biologically harmful even in very low concentrations.

The industrial contribution to hazardous wastes

Industries are by far the largest sources of hazardous waste: in 1986, Canadian industries produced an estimated 8 million tonnes of it. Consumers also generate hazardous wastes whenever they discard paint, solvents, old batteries, pesticides, cleaners, and many other household products. It has been estimated that the average Canadian consumer is responsible for 2.5 kg of hazardous waste a year (Commission d'enquête sur les déchets dangereux 1990). Nationally, consumers produce a total of more than 60 000 t of hazardous waste material, but this amounts to only about 1% of the industrial contribution. Biomedical wastes are another type of hazardous waste that is subject to control, but these account for only an estimated 8 300–31 300 t per year, or less than one-half of 1% of all hazardous wastes.

Whereas industries have made important strides in reducing many types of air and water pollution, the situation with regard to hazardous wastes is probably getting worse. The most industrialized provinces were the heaviest producers of hazardous wastes, with Ontario contributing 59% of the national total in 1986, and Quebec 21%.

One reason hazardous wastes have become such a high-profile environmental issue in recent years is that they have been so badly handled in the past. Until relatively recently, highly toxic wastes were often dumped in insecure landfills, and decommissioned industrial sites were routinely abandoned without being properly cleaned up. Contamination from these sources has been the cause of a number of major environmental problems. Improperly stored toxic wastes on the American side of the Niagara River are now one of the major sources of water pollution in Lake Ontario. These wastes, which seep into the groundwater from leaking storage containers, are a witch's brew of formidable chemicals, including organochlorine pesticides and PCBs. It was contamination from one of these sites, the Love Canal, that forced more than 1 000 families to abandon their homes in the late 1970s. In Canada, the careless disposal of low-level radioactive wastes in the Port Hope, Ontario, area during the 1940s also led to the later abandonment of residential areas.

It is estimated that as many as 1 000 contaminated sites may currently exist in Canada. Of these, some 3–5% are "orphan" sites (T. Foote, Environment Canada, personal communication) for which no owner can be traced or held responsible. Cleaning up these sites is now a task of some urgency. In October 1989, the Canadian Council of Ministers of the Environment announced a program to ensure the remediation of high-risk contaminated sites. The parties responsible for the contamination, when they can be identified, will bear the costs of cleanup; in the case of orphan sites, however, governments will have to absorb the costs.

Disposing of hazardous wastes

Current practices seek to avoid contamination problems by destroying or detoxifying hazardous wastes and then disposing of the residues securely. In the case of substances that cannot be neutralized, such as high-level radioactive wastes, much more serious consideration has now been given to the problems of disposal. The approach currently favoured for such wastes is deep underground burial in stable rock formations.

Many hazardous wastes can be captured and detoxified at source through simple procedures such as filtration and the addition of neutralizing chemicals. Caustic liquids, for example, can be safely neutralized with acids to produce a simple salt and water solution. Some wastes, such as oils, can be degraded biologically through the action of microorganisms. Some other wastes that cannot be disposed of by these processes can be destroyed by means of controlled, high-temperature incineration. This is the most effective way of disposing of persistent toxic chemicals such as PCBs and organochlorine pesticides. Such incinerators operate at very high standards of efficiency and are designed to achieve 99.9999% destruction of PCB wastes.

In 1986, approximately 65% of hazardous wastes in Canada were managed on site, that is, at the place where they were generated (Environment Canada 1986). Smaller companies unable to afford their own waste disposal facilities and companies with wastes requiring very expensive disposal procedures usually opted for off-site management (see Box 14.2), where the costs could be shared by several users.

Although off-site management is often the only practical alternative in many situations, it does involve additional environmental risks. These are associated with the need to store hazardous wastes while they await treatment and then to transport them to the disposal facility. Stored wastes can be released to the environment accidentally through leaks, spills, and fire. The burning of a warehouse containing PCB wastes in St-Basile-le-Grand near Montreal in 1988, forcing the evacuation of 3 500 residents, is a forceful reminder of these dangers.

The possibility of an accidental release is even greater during transportation than during storage. Hazardous wastes are dangerous goods and therefore fall under the *Transportation of Dangerous Goods Act* if carried across provincial or international boundaries and under provincial regulations if movement is within or between provinces. As well as specifying requirements for equipment, procedures, personnel training, and emergency preparations, these regulations require shippers to provide documentation that allows the shipment to be tracked at every point of its journey. If waste does not arrive at its destination, the authorities are notified. Generators of hazardous waste are responsible for its proper handling at every stage.

Imports and exports of hazardous wastes represent a small but significant component of these shipments. Nearly 300 000 t of hazardous waste crossed the Canada–U.S. border in 1990, with Canada importing slightly more (about 6 700 t) than it exported (Fig. 14.8). Canada has increased its exports of hazardous wastes to the United States substantially in the past few years, and this shift may reflect the fact that there are more treatment facilities there. Transborder shipments may also involve shorter distances and therefore present a lower risk. The same logic also applies to the movement of hazardous wastes across provincial boundaries.

As the costs of disposal rise, with the increasing stringency of controls in North America, some generators may be tempted to seek cheaper disposal options in less regulated countries that may be unable to manage hazardous wastes safely. To provide more international control over these shipments, the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal will establish uniform procedures for countries to follow when hazardous wastes cross international borders. The convention provides for notification and written consent prior to shipment of hazardous wastes, liability insurance to cover exporters, importers, and carriers, reporting, and the return of shipments that cannot be managed to the originator. New regulations to control the export and import of hazardous wastes, expected to be in place by 1992, will allow Canada to ratify the Basel Convention.

More stringent treatment requirements may also increase the incentive for unscrupulous originators to dispose of their wastes illegally. At the present time, a shockingly large amount of hazardous waste is not controlled properly, through either mismanagement or deliberate avoidance of disposal regulations. A recent Quebec study, for example, could not account for nearly a third of the wastes sent off site for treatment in the province (Commission d'enquête sur les déchets dangereux 1990). Some of these wastes are undoubtedly contaminating the environment, but, because their location is unknown, remedial action cannot be taken. The potential for extremely serious environmental and health problems in a situation of this kind is considerable, and much tighter controls will be needed to ensure that all hazardous wastes are disposed of safely.

BOX 14.2

Not in my backyard: the problem of permanent treatment sites

At the present time, we are generating hazardous wastes faster than we can dispose of them, with the result that untreated wastes are accumulating in storage locations in increasing quantities. The main problem is a lack of permanent off-site treatment facilities capable of handling those wastes that are most difficult to manage. Both industries and society in general have been slow to recognize and respond to this need. Indeed, Canada's first comprehensive, integrated hazardous waste treatment facility, at Swan Hills, Alberta, was not opened until September 1987.

Similar facilities are planned for other areas in Canada, but frequently the choice of sites has been complicated and delayed by local opposition. Although the actual hazards posed by these facilities may be small, citizens fear the occurrence of toxic nightmares in their neighbourhoods and are reluctant to live with the perceived risks, even when they acknowledge that the facility itself may be of some benefit to society (Connor 1990).

Typically, disposal sites have been chosen primarily on the basis of technical considerations such as proximity to industrial centres and environmental soundness. Although citizens are invited to express their concerns once a suitable site has been identified, the decision to build the facility on the chosen site is usually seen as a *fait accompli*. In these circumstances, citizens often become distrustful of public officials and see a vigorous campaign of opposition as their only hope of affecting the outcome (Armour 1988).

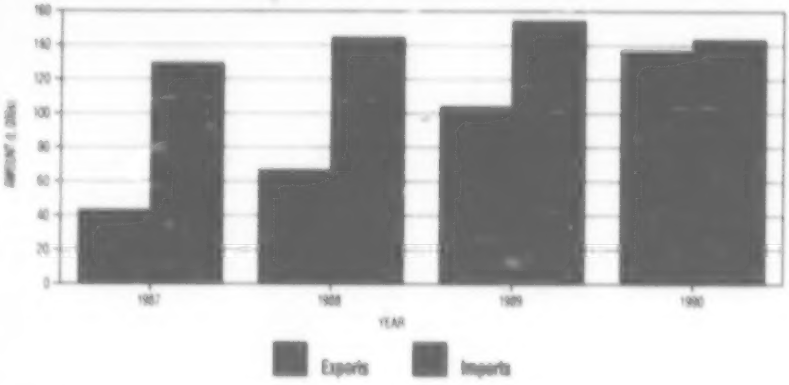
A more successful approach to site selection has been developed in Alberta and was used by the Alberta Waste Management Corporation in choosing the Swan Hills site. Under this approach, unsuitable areas are first eliminated on the basis of technical and environmental standards. Town councils in the remaining areas are then asked if they would like further assessments to take place within their jurisdictions. After these assessments are completed, councils are invited to make proposals for the siting of the facility in their area. In the case of the Swan Hills facility, five communities expressed an interest, and all sought public reaction to the proposal. The advantage of this approach is that it leaves the communities free to decide if they want the facility and results in a faster and less combative selection process (Champion 1990).

The expansion of existing private facilities provides another means of increasing our capacity for treating hazardous wastes. Because these facilities are already in existence, their expansion creates less opposition than the construction of new facilities in communities that have not had any previous experience with hazardous waste operations.

While debates over the siting of permanent facilities go on, the federal government has turned to mobile incinerators as a way of dealing with the problem of PCB wastes that are now in storage in some 3 000 sites across the country. These incinerators will be moved to various locations in the country where the volume of PCB wastes warrants their operation. By taking the incinerator to the wastes, this approach minimizes the risk of transportation mishaps. Moreover, because the incinerator remains in one locality for only a matter of months, public reaction to its presence is more favourable.

FIGURE 14.8

International movement of hazardous waste, 1987–90



Source: Environment Canada, as provided by the provinces.

TABLE 14.2

Disposal of hazardous wastes (in tonnes)

Disposal method	Quebec 1989	Quebec 1990	Ontario 1989	Ontario 1990	Alberta[a] 1989	Alberta[a] 1990	British Columbia 1989	British Columbia 1990
Storage	45 000	45 000	253 358	278 215	0	0	7 781	14 587
Incineration			64 445	45 141	3 834	3 798	3 694	6 803
Chemical/ physical treatment	—	—	—	—	102	87	2 886	6 279
Biological treatment	—	—	466 667	605 145	—	—	635	729
Secure landfill	100 000	100 000	274 668	242 356	27 587	8 042[b]	4 152	2 217
Recycling	—	—	226 701	211 686	7 981	28 905	14 093	17 017
Reused (distillation, etc.)	—	—	—	—	—	—	—	—
Fate unknown	—	—	—	—	—	—	84 848	102 207
Total	**145 000**	**145 000**	**1 442 941**	**1 580 478**	**39 504**	**40 832**	**136 611**	**170 781**

[a] Data do not include hazardous wastes treated or disposed of on site and hazardous wastes associated with drilling and production of crude oil and natural gas.

[b] Asbestos was dropped from Alberta's hazardous waste manifest system in 1990, partially explaining the large drop in waste going to secure landfill.

Source: G. Legault, Ministère de l'environnement du Québec, personal communication; F. Jager, Ontario Ministry of the Environment, personal communication; S. Lupul, Alberta Environment, personal communication; K. Hicke, B.C. Ministry of the Environment, personal communication.

Reducing and recycling hazardous wastes

Many problems could be avoided if we could reduce our output of hazardous wastes in the first place. Some wastes can be substantially reduced or eliminated altogether by changes in manufacturing processes or the use of alternative chemicals. Other wastes can be reused, either as is or with reprocessing. A study of the hazardous wastes generated in Canada in 1986 estimated that about half of them had a high potential for recycling (Environment Canada 1986). However, industries have been slow to take advantage of this opportunity, because of a failure either to recognize the possibilities of recycling or to make the necessary investment in it. In Ontario, less than 15% of the wastes managed off site are being reclaimed or recycled (Table 14.2). There are some positive signs, however: in Alberta, the volume of hazardous waste being recycled increased by 350% from 1989 to 1990.

One practice that holds promise for improving the recycling of hazardous wastes is the exchange of wastes between generating companies and companies that can use the waste products in their operations. The federal government and most provincial governments actively assist this process through the operation of waste exchanges that match the needs of potential users with supplies available from producers. Although these programs account for only a small fraction of the wastes managed off site, they have good prospects for growth (Table 14.3). The proposed Export/Import Regulations being developed under the *Transportation of Dangerous Goods Act* will try to facilitate recycling by providing alternative controls for hazardous wastes destined for recycling operations. Canadian governments are committed to reducing the volume of hazardous waste generated by 50% of 1988 amounts by the end of the century.

The beginnings of a solution

Although industries have made convincing progress in reducing releases of many air and water pollutants, they have not been nearly as effective in dealing with hazardous wastes. Unlike air and water pollution, hazardous wastes are largely an industrial problem, and the solutions to it involve important changes in industrial practices, particularly in terms of reducing the output of hazardous wastes and recycling more of the wastes that are produced. Governments can assist in developing the infrastructure to manage hazardous wastes and in ensuring better enforcement of disposal regulations. There are signs that industries are now attempting to improve their performance. The Canadian Chemical Producers' Association, for example, has recently committed its members to a comprehensive cradle-to-grave management plan for chemical products (see Chapter 21). However, it will be a few years before these and other actions begin to bear fruit.

TABLE 14.8

Hazardous waste materials exchanges (in tonnes)

Hazardous waste type	Canada[a]		Ontario[b]		Manitoba[b]		Alberta[b]	
	Fy 1988/89	Fy 1989/90	1988/89	1989/90	1989	1990	1989	1990
Total[c]	**236 750**	**249 382**	**1 021**	**2 367**	**N/A**	**N/A**	**N/A**	**N/A**
Acids/alkalis	15 197	18 834	197	54	0	0	1 607	1 809
Organic/inorganic	4 848	6 808	521	43	21.1	18.9	614	2 120
Oils/fats, waxes	33 630	36 394	34	101	3.7	96	N/A	N/A
Metals/metal-containing sludges	17 594	18 552	269	2 109	0	0	900	N/A

[a] Fy = fiscal year (April 1–March 31).

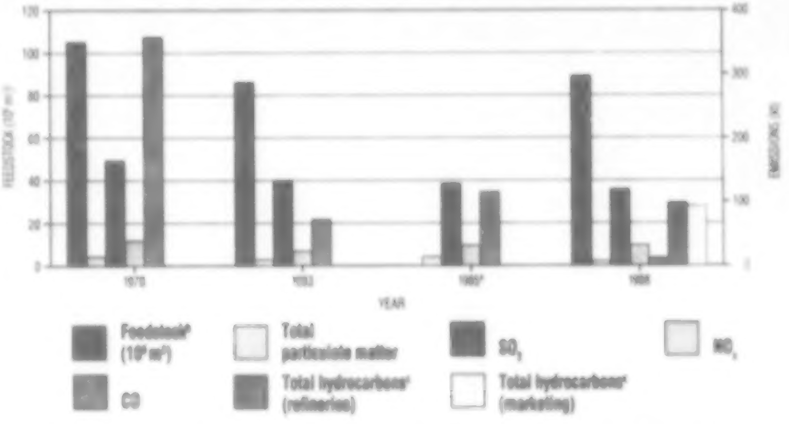
[b] The figures are underestimates, based on an incomplete data set (N/A = not available). Wastes associated with drilling and production of crude oil and natural gas are not defined as hazardous waste in Alberta.

[c] Does not include the British Columbia Waste Exchange Program.

Source: R. Laughlin, Ortech International, personal communication; L. Varangu, Ortech International, personal communication; B. Candlish, Biomass Energy Institute, personal communication; W.C. Ray, Alberta Research Council, personal communication.

FIGURE 14.9

Canadian petroleum refinery emissions estimates



[a] Environment Canada estimates using the 1983 Petroleum Association (PACE) methodology and provincial input.

[b] From Padgett Process Services NO_x reduction study (including 4.7 kt for catalytic cracking).

[c] No reliable data until 1988.

THE INDUSTRIAL RECORD: SOME CASE STUDIES

Petroleum refining

In 1987, there were 29 petroleum refineries in Canada, processing an average of 248 000 m³ of crude oil every day (Losier 1990). As an industry, it generates many types of air and water pollutants, as well as solid wastes.

The most common air pollutants released from petroleum refineries are carbon monoxide, sulphur oxides, nitrogen oxides, particulates, and hydrocarbons. Lesser emissions of foul-smelling substances such as hydrogen sulphide, mercaptans, aldehydes, ammonia, and phenolic compounds also occur. As Figure 14.9 shows, refinery emissions of all of these substances have declined since 1978, most of them substantially.

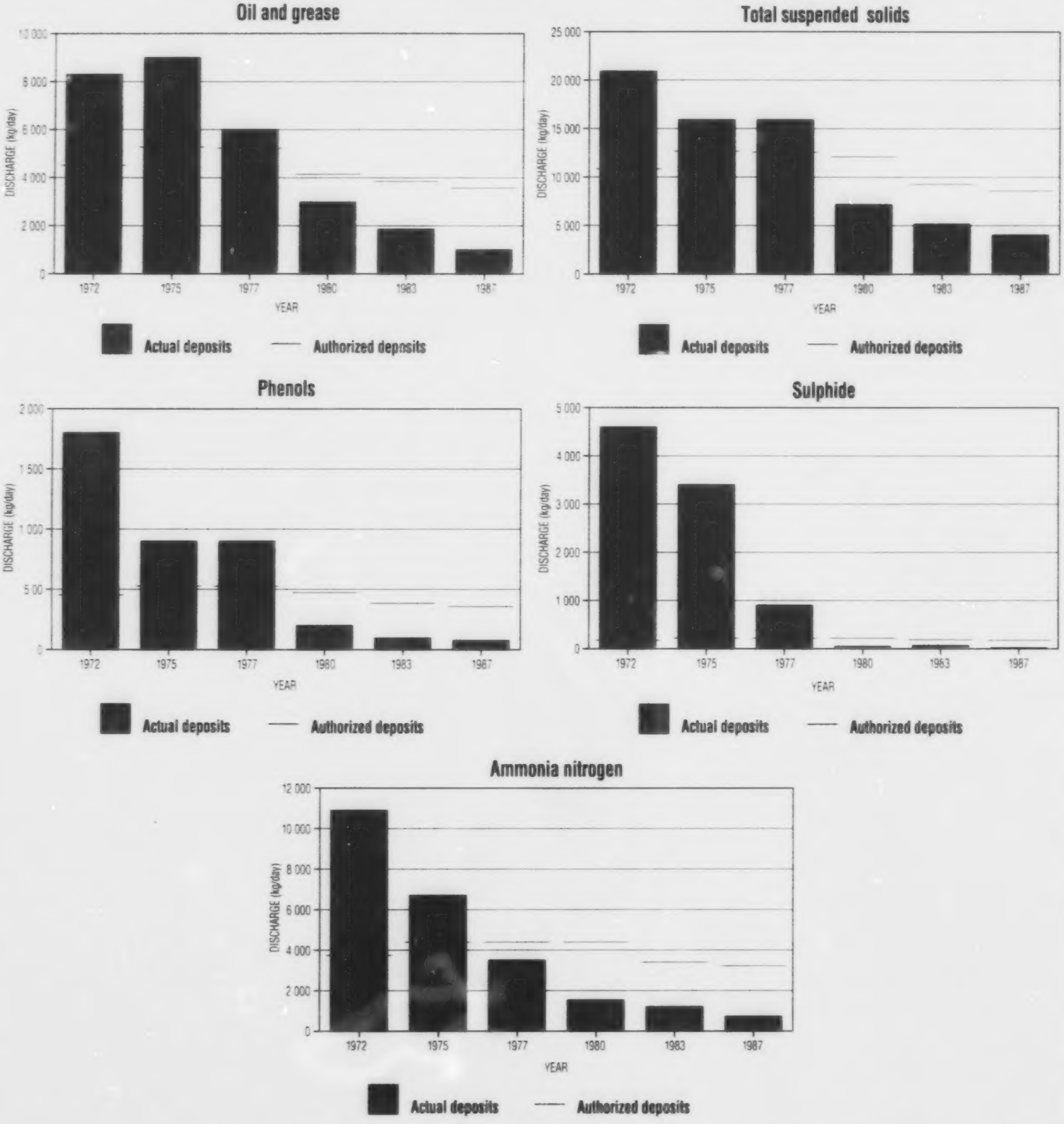
Refinery wastewaters can be contaminated by crude oil, acid catalysts, and a bewildering assortment of process chemicals, including caustic soda, sulphuric and phosphoric acids, amines, sulpholane, furfural, glycols, ammonia, detergents, nutrients for biotreatment, and additives for foam suppression, corrosion inhibition, and water treatment. Reaction products and product additives such as corrosion inhibitors, anti-knock compounds, and anti-icing compounds can also end up in the refinery sewer.

The principal contaminants in refinery discharges are oil and grease, suspended solids, phenols, sulphides, and ammonia nitrogen. As Figure 14.10 shows, Canadian refineries have greatly improved their management of these wastes, and discharges dropped spectacularly between 1972 and 1987. Currently, 81% of Canadian refineries apply secondary or tertiary treatment to their effluent (Losier 1990).

Sludges accumulate in storage tank bottoms, whereas other solid wastes come from spent catalysts and alumina, clay, and sand used in filters. Tank bottom sludges may contain volatile compounds such as benzene, toluene, and ethylbenzene, as well as phenols and PAHs. Trace metals, including iron, chromium, lead, mercury, zinc, copper, and vanadium, may also be present. Approximately 30% of these wastes are reused or recycled, 36% are disposed of in landfill sites, 18% are

FIGURE 14.10

Average annual discharges from Canadian petroleum refineries, 1972–87



Source: Losier (1990).

spread on land, 7% are incinerated, 1% are injected into deep wells, and the remainder are disposed of by a variety of other methods.

Chemical manufacturing

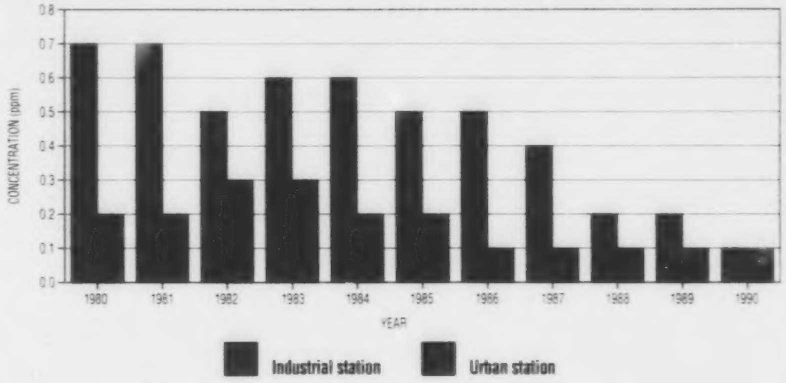
Chemical manufacturing is by far the most complex industry in Canada, manufacturing or importing an estimated 21 400 chemicals. The largest component, accounting for 60% of Canadian chemical production, is the petrochemical sector. Approximately half of all Canadian petrochemical production is in Alberta, and another 35% is in Ontario.

Many of the raw materials and intermediate products in chemical manufacturing, as well as end products and wastes, are gaseous or volatile and can easily escape to the air through leaks and accidental discharges, as well as through smokestack emissions. VOCs make up a significant proportion of these emissions. According to a 1988 survey, the chemical industry emits some 35 000 t of VOCs annually (Environment Canada 1990*a*).

The range of raw materials and processes employed in the chemical industry results in process wastewaters of varying composition. A wide variety of pollutants — including both conventional and persistent toxic contaminants — originate from raw materials, reactants, products, and by-products and occur over a wide concentration range. Conventional pollutants that may be present in the wastewaters of chemical manufacturing industries include acids, bases, suspended solids, oil and grease, organic carbon, and nitrogen. Toxic pollutants that may be present include metals, phenols, chlorinated hydrocarbons, and PAHs.

FIGURE 14.11

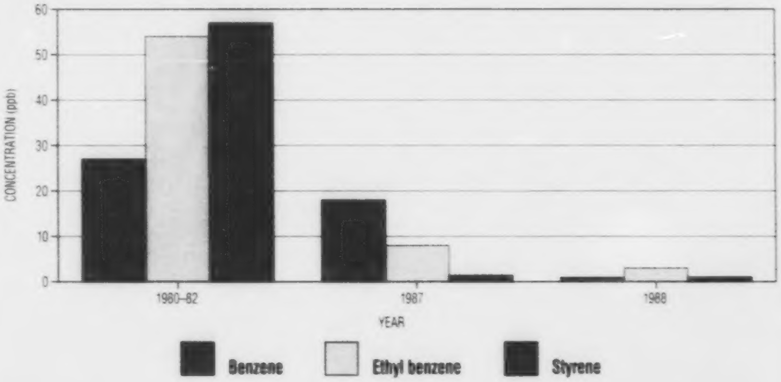
Annual average levels of nonmethane hydrocarbons, Sarnia, Ontario, 1980–89



Source: Lambton Industrial Society (1990)

FIGURE 14.12

Selected organic chemicals found in fish flesh in the St. Clair River, 1980–88



Note:

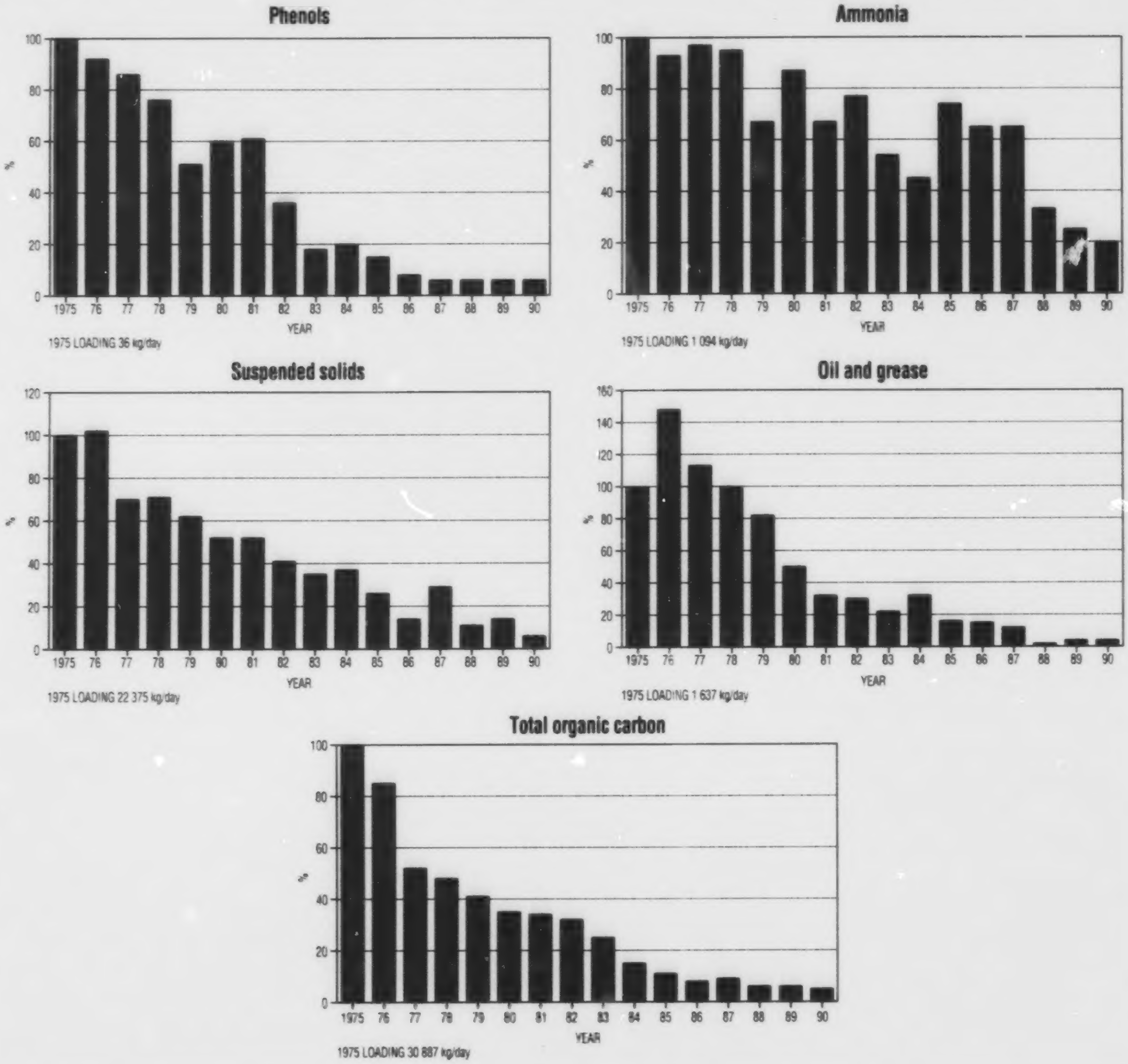
	1980–82	1987	1988
No. of fish sampled	18	10	10
Avg. river exposure time	24 h	8.3 mo.	15.5 mo.

Source: Lambton Industrial Society (1990).

Chemical industries have made a considerable effort to reduce their emissions and discharges. As a result, the impact of individual facilities on the local environment has moderated substantially since the late 1960s and early 1970s. These changes are apparent in various environmental indicators for the vicinity of Sarnia, Ontario, which contains one of the highest concentrations of petroleum refineries and petrochemical plants in the country. During the 1980s, nonmethane hydrocarbon levels in the Sarnia industrial area (where industrial emissions predominate) dropped by nearly two-thirds (Fig. 14.11). The decline in hydrocarbon levels is also reflected in the very large decrease in selected organics measured in the tissues of locally caught fish (Fig. 14.12). Figure 14.13

FIGURE 14.13

Discharges of commonly monitored water pollutants from industries in the Sarnia, Ontario, area



Phenols

1975 LOADING 36 kg/day

Ammonia

1975 LOADING 1 094 kg/day

Suspended solids

1975 LOADING 22 375 kg/day

Oil and grease

1975 LOADING 1 637 kg/day

Total organic carbon

1975 LOADING 30 887 kg/day

Source: Lambton Industrial Society (1990).

shows a similar improvement in the quantities of phenols, ammonia, suspended solids, oil and grease, and total organic carbon discharged by local industries in their wastewater.

Pulp and paper production

Pulp and paper is one of Canada's largest and most ubiquitous industries, with mills operating in every province except Prince Edward Island.

The production of pulp and paper requires large quantities of water. On average, each tonne of paper requires slightly more than 100 m^3 of water, although the actual amount consumed depends on the production process. The use of such large quantities of water produces a large volume of liquid waste, which contains wood fibres, finely divided solids, and a complex mixture of compounds derived from wood and the chemicals used in production processes.

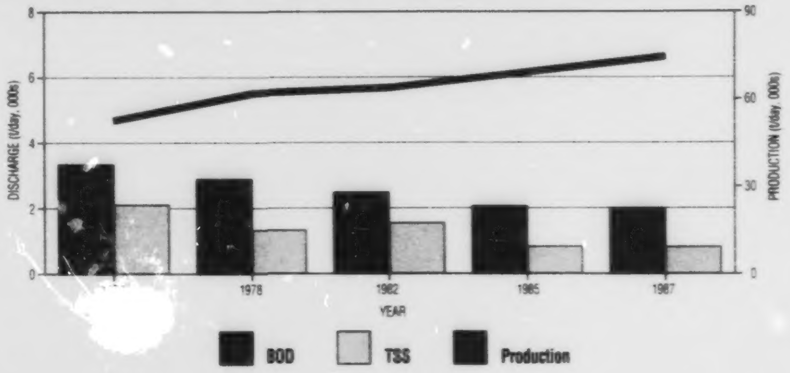
In addition to large amounts of BOD and total suspended solids (TSS), the final effluent from these mills can contain resins, fatty acids, and sulphur compounds that are acutely toxic to fish. Mills using chlorine for bleaching have also been identified as a significant source of dioxins and furans, which are discharged in the wastewater. Although total releases amount to only 100 –150 g per year of 2,3,7,8-TCDD and 2000–3000 g per year of 2,3,7,8-TCDF (Environment Canada/Health and Welfare Canada 1990), the high toxicity of these substances makes them a matter of considerable concern. As of 1990, 47 mills in Canada used chlorine bleaching (Canadian Pulp and Paper Association 1990). Regulations have recently been issued under the *Canadian Environmental Protection Act* (CEPA) requiring these mills to modify the bleaching process by 1993 in order to prevent the formation of dioxin and furan contaminants.

In 1991, 125 of Canada's 155 mills discharged their effluent directly into a body of water rather than into a municipal sewer system. In spite of increased production, these mills have made some substantial improvements in the quality of their effluent. As Figure 14.14 shows, discharges of TSS declined from 2 106 t per day in 1978 to 816 t per day in 1985, whereas discharges of BOD fell from 3 337 to 1 961 t per day during the same period. New regulations introduced under CEPA in 1991 require further reductions in these pollutants.

Although pulp and paper mills have always recycled their internal waste paper, many are now recycling postconsumer paper waste. Out of 110 paperboard mills, 40 depend on postconsumer paper for raw material.

FIGURE 14.14

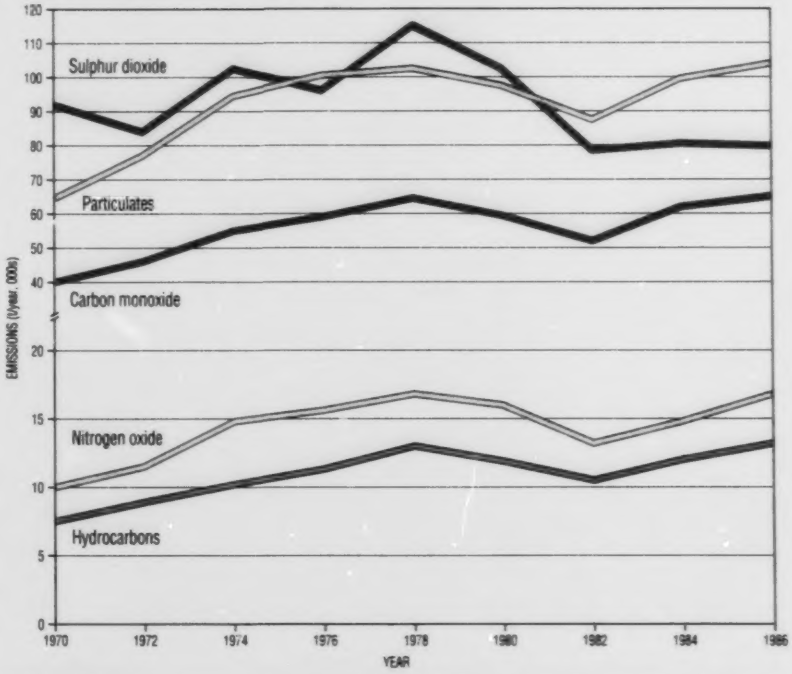
Discharges from Canadian pulp and paper mills, 1970–87



Source: Environment Canada, Industrial Programs Branch.

FIGURE 14.15

Estimated annual emissions of common air pollutants from the pulp and paper industry, 1970–86



Source: Sinclair (1990).

Whereas pulp and paper mills have made important improvements in their control of liquid wastes, they have been less successful at reducing their output of air pollutants. Malodorous sulphur emissions, which can be detected 50 km or more from a mill, are a particular problem. As Figure 14.15 shows, the industry's emissions of common air pollutants between 1970 and 1986 have gradually increased, with the exception of sulphur dioxide. In general, increases in these emissions have reflected increases in production (Sinclair 1990).

BOX 14.3

Consumers and pollution

It is easy to see industries as the villains that have created the bulk of our pollution problems. However, consumers also bear an important measure of responsibility. Not only is a good deal of manufacturing driven by consumer demand, but consumers themselves contribute directly to air, water, and solid waste pollution.

VOCs, for example, are widely used as solvents and carriers in nail polishes, perfumes, rubbing alcohols, glues, furniture polish, oil-based paints and thinners, and other household products, as well as in products for auto care and maintenance. Personal care products alone accounted for the release of 22 000 t of VOCs, or 4% of the 502 000 t released from all solvent uses in Canada in 1988 (Table 14.B1). Household cleaners and polishes accounted for a further 11 500 t (2%), auto care and maintenance products for 37 000 t (7%), and aerosol containers and propellants for 11 000 t (2%). In total, 15% of all VOC releases are from consumer products used by the average householder. An additional 14 000 t, or 3% of VOC releases, were emitted by dry-cleaning operations, again a service driven by consumer demand. Even gardening activities contribute to pollution through the use of pesticides, herbicides, fertilizers, and other chemical products.

Many of our environmental problems result from our own activities as consumers. Nowhere is this truer than in the case of the family car, whose total impact on the environment is truly formidable. The following is a brief catalogue of the many ways in which a car affects the environment during its life cycle.

As Table 14.B2 shows, the building of an average car requires large quantities of many different raw materials — iron, steel, copper, aluminum, rubber, ceramics, glass, fabrics, plastics, vinyls, and other products. About 14% of all Canadian steel production (2 million tonnes) is for motor vehicles. The production of all of these materials consumes enormous amounts of energy, minerals, water, and petroleum products and generates huge volumes of waste. Much of this waste consists of hazardous materials, such as oil and lubricants, acids, paint, and solvents.

Cars consume land, too, for roads, parking lots, and road-building materials. Much of this is prime agricultural land that cannot be replaced. In 1985, Canada had a total of 841 411 km of roads. Considering that even ordinary arterial roads have an average right-of-way of 34 m, the land area occupied by roads is considerable.

Cars burn fuel for energy and, in doing so, create pollution. The total amounts of energy consumed and pollution released are, in part, a function of the number of cars on the road and the distance they drive. Between 1970 and 1985, the number of motor vehicles on the road increased by 70% (Hilborn and Still 1990). By 1990, each household in Canada owned 1.3 cars (Statistics Canada 1990), and each of these drove approximately 17 400 km per year, 2 100 km more than in 1979. Not surprisingly, this growth has meant that motor vehicles have been consuming a steadily increasing proportion of our petroleum resources. In 1958, the transportation sector accounted for 48% of Canada's total petroleum energy consumption; by 1986, it had increased to 63%, with cars and trucks accounting for 80% of energy used for transportation (Energy, Mines and Resources Canada 1988).

Emission inventories compiled at various times between 1985 and 1988 indicate that cars released 37.2% of all the carbon monoxide from human sources in Canada, as well as 26.2% of the VOCs, 22.6% of the total hydrocarbons, 20.0% of the nitrogen oxides, 10.3% of the carbon dioxide, 2.5% of the total particulates, and 0.3% of the sulphur dioxide (Tom Furmanczyk, Environment Canada, personal communication; Jaques 1990). In addition, air conditioners in private cars and trucks contributed 7.9% of Canada's CFC emissions in 1988 (Environment Canada 1990*b*).

Cars represent a significant source of water pollution and hazardous waste as well, mostly from improperly discarded motor oil. In 1986, it was estimated that 425 million litres of contaminated waste oil were generated in Canada, of which some 70% was used or disposed of in an environmentally unacceptable manner (Environment Canada 1986).

Since the mid-1970s, serious efforts have been devoted to making the car more environmentally benign. Fuel consumption has been improved by making bodies smaller and lighter and by making engines more fuel-efficient. Pollutant releases have been substantially reduced by the use of catalytic converters and by changes in fuel chemistry, particularly the elimination of alkylated lead additives and reductions in fuel volatility. Because of these improvements, emissions of some pollutants from the transportation sector have stabilized or even decreased in spite of the increased number of vehicles.

TABLE 14.81

Estimates of solvent usage and VOC emissions (in thousands of tonnes per year) in Canada, 1988

Solvent uses	Solvent used[a]	VOCs emitted[b]
Paint/coating applications	187.5	187.5
Glues/adhesives/sealants	35	35
Printing	38.5	20
Industrial degreasing	34	17.5
Dry cleaning	14	14
Consumer products:		
Auto care/maintenance	121	37
Household cleaners/polish	11.5	11.5
Personal care products	22	22
Aerosol propellants	15	11
Pesticides	11	11
Other:		
Pharmaceuticals & food processing	2.2	2
Natural oils extraction	10	10
Photocopy	1	1
Paint strippers	6	2
Wood preservation	2	2
Oilfield chemicals	18	18
Rubber products	4.5	4.5
Petroleum refining	1.5	1.5
Polyolefin manufacture	4.5	4.5
Blowing agents	10.2	–
Mining	5.0	5
Calendering	3.0	3
Electronics manufacture	1.0	–
Metal rolling	1.0	1
Refrigerant	8.5	–
Water treatment	1.5	1.5
Miscellaneous	81	79.5
Totals	**650.9**	**502**

[a] Summary of estimates developed by P.G. Miasek of ESSO Chemicals Canada, based on published information. Quantities of solvents whose end uses are as fuel or conversion to another substance are not included in these totals.

[b] VOC emission estimates developed by Levelton & Associates and Environment Canada. Nonreactive solvents are not included in the emission estimates. Where emission reduction information is inadequate, it is assumed all reactive solvents used are eventually emitted.

Source: Canadian Council of Ministers of the Environment (1990).

CONCLUSIONS

How significant are industrial plants as sources of pollution in the 1990s? Certainly they can no longer be seen as the sole, or in many cases even the predominant, villains of environmental pollution, as they were in the early years of the century. Since the 1970s, industries in general have softened their impact on the environment. Other economic activities as well as the average citizen, in his or her role as a consumer, have also been identified as a factor in environmental pollution (see Box 14.3).

Industrial plants have improved their environmental record most successfully in the areas of air and water pollution. These improvements may be ascribed to a number of factors. A very substantial tightening of government legislation and regulation has undoubtedly had a lot to do with it. However, other factors have been important as well. In some cases, economic incentives have encouraged manufacturers to make efficiency improvements that have also yielded significant environmental benefits in terms of reductions in pollutants. Moreover, as public opinion has become more environmentally conscious, many industries have come to realize that their environmental sins may come back to haunt them if they do not control their pollutants more effectively.

If industries are no longer the great villains of the environmental scene, they are not yet saints either. Parts of the industrial house still have to be put in better order. Hazardous wastes, in particular, need to be managed more effectively and diminished substantially. Discharges of liquid wastes need to be controlled more consistently. Even in the area of air pollution, where major improvements have been made, much more needs to be done.

The industrial revolution has brought us many benefits, and few of us would choose to live without them. At the same time, society has recognized that these benefits have often been achieved at an unacceptable cost in terms of environmental degradation. To maintain these benefits — or at least those that are most essential — without destroying the capacity of the environment to sustain itself is now the task ahead of us. Once the most visible historical polluters, industrial plants in the last 20 years have begun to realize their responsibility for maintaining a healthy environment. Some have not always done so willingly or altruistically, but many have acted pragmatically. Much more remains to be done, but the progress achieved thus far suggests that industries can operate in a way that is much less damaging to the environment than in the past.

TABLE 14.B2

Material requirements of the average passenger car[a] (in kilograms)

Material	1977	1983	1985	1987	1989
Plain carbon steel	906.8	686.8	673.4	663.2	643.6
High-strength steel	56.8	94.1	98.9	103.6	106.4
Stainless steel	11.8	12.7	13.2	14.5	14.1
Other steel	25.5	24.1	24.8	25.2	21.4
Iron	245.5	215.5	212.7	209.1	208.6
Plastics/composites	82.0	91.2	96.1	100.7	102.0
Fluids & lubricants	90.9	83.2	83.6	83.2	81.6
Rubber	68.2	62.5	61.8	61.6	61.1
Aluminum	44.1	61.8	62.7	66.4	70.7
Glass	39.1	38.6	38.6	39.1	38.6
Copper (mechanical & electrical components)	16.1	17.7	20.0	20.9	22.5
Zinc die castings	17.3	8.0	8.2	8.2	9.1
Powdered metal components	7.0	8.2	8.6	8.9	9.8
Other materials	60.7	46.8	46.1	40.0	37.7
Total	**1671.8**	**1451.2**	**1448.7**	**1444.6**	**1427.2**

[a] Estimates are based on U.S.-built models only, including family vans and wagons.

Source: Ward Communications (1989).

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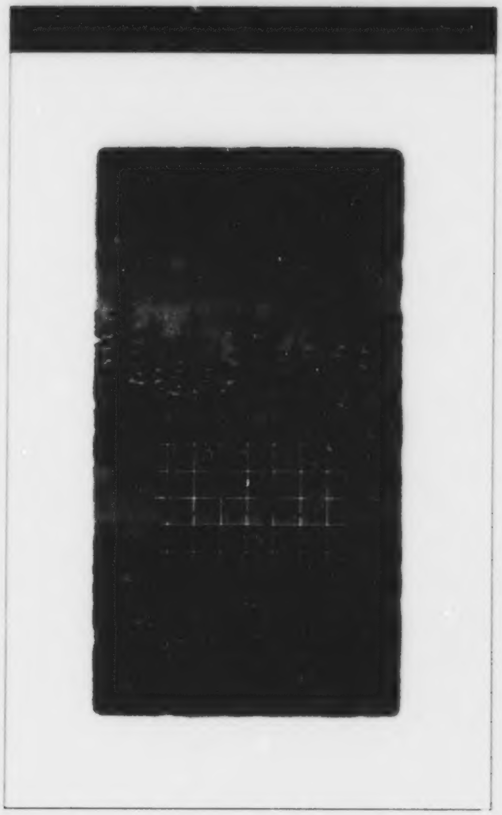

PART III

REGIONAL CASE STUDIES

15

COURTESY OF J.R. REID NIPLAN

HIGHLIGHTS

The Arctic has sparse human populations but nonetheless has localized environmental problems with mining, oil and gas, and community wastes. Most substances decay more slowly at colder temperatures and under reduced sunlight.

■

Oil degrades slowly in the arctic cold: 10–25 times more slowly at 5°C than at 25°C. For this reason and because ice cover reduces the spreading and evaporation of oil, biota and their natural habitat may be exposed to the contaminant for a longer time than in temperate waters.

■

Many heavy metals and chlorinated organic compounds with origins in major industrialized regions of the world are appearing in the Arctic. These contaminants have been carried into the Arctic by atmospheric circulation, rivers, and ocean currents, and there, for geophysical reasons mainly to do with the cold, they tend to remain trapped. This ongoing transfer of pollution is the most significant threat to environmental quality in the Arctic.

■

Research shows that levels of certain contaminants are declining and others are increasing. Trends within the Arctic of contaminants from distant sources can serve as indicators of the rate and extent to which these pollutants are entering the global environment.

■

Most Inuit eat substantial amounts of wild game and, as a consequence, accumulate toxic substances from the industrialized world. Although there may be risks to Inuit health from consuming contaminated "country foods," there are major benefits associated with the nutrients present.

■

Over the six years 1991–97, the Arctic Environmental Strategy of the Green Plan will monitor water pollution and long-range transport of contaminants and determine the impacts on the northern ecosystem and native diets, clean up waste disposal sites, and assist communities in meeting economic and environmental objectives.

■

On an international scale, Canada is a signatory to several multilateral and bilateral agreements and conventions aimed at protecting the arctic ecosystem and its resources.

■

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> **The North is the only place where Nature can still claim to rule, the only place as yet but little vexed by man. All over the globe there spread his noisy failures; the North alone is silent and at peace. Give man time and he will spoil that too.**
>
> — Stephen Leacock (1937)

INTRODUCTION

Although once considered pristine because of its remoteness and small population, over the last 50 years the Canadian Arctic has been subjected to contaminants from local mining, oil and gas, and community activities as well as pollutants transported over long distances from industrialized regions of the world. Although there are lower levels of these contaminants in the Arctic than in southern Canada, they are of greater concern in the North because of their persistence in the arctic environment and their potential to accumulate in the tissues of wildlife species that constitute a substantial portion of the diet of arctic residents.

This chapter briefly describes the arctic ecosystem and its unique vulnerability to contamination, then focuses on the various human activities that are currently stressing the ecosystem, the levels of contaminants observed in the environment, and known effects on biota. The potential effects on health due to consumption of contaminated foodstuffs by native people in the Arctic are examined next. Finally, the responses of the Canadian government to these stresses on the arctic ecosystem are highlighted.

THE ARCTIC ECOSYSTEM

Geographic extent

In its most literal sense, the word "Arctic" refers to the area north of the arctic circle (66° 30' N latitude); the Arctic Ocean would also be included in this definition. However, to most Canadians, "Arctic" conjures up images of cold climate, sparse, dwarfed vegetation, polar bears, and ice-infested seas. Based on these perceptions, natural boundaries defined by tree line and climatic features perhaps best reconcile the image of the Arctic with a definable boundary on land.

For the purposes of this chapter, the Arctic can be defined as the arctic life zone and the arctic portions of the marine life zone (see Chapter 6), which are those terrestrial areas north of the tree line experiencing continuous permafrost and mean temperatures less than 10°C in the warmest month, less than -30°C in the coldest month, and below -10°C average for six or more months of the year. This region, which encompasses 24% of Canada's land area and more than two-thirds of Canada's 244 000 km of coastline (Fig. 15.1), includes all the islands of the Arctic Archipelago, northern Yukon, much of the Northwest Territories, northern Quebec and Labrador, and oceanic regions north of 60°N and Hudson and James bays. It is the most sparsely populated portion of the country, with fewer than 45 communities and a total population of only 27 000 people (about 0.1% of Canada's total population), virtually all of whom live in coastal communities (Statistics Canada 1989).

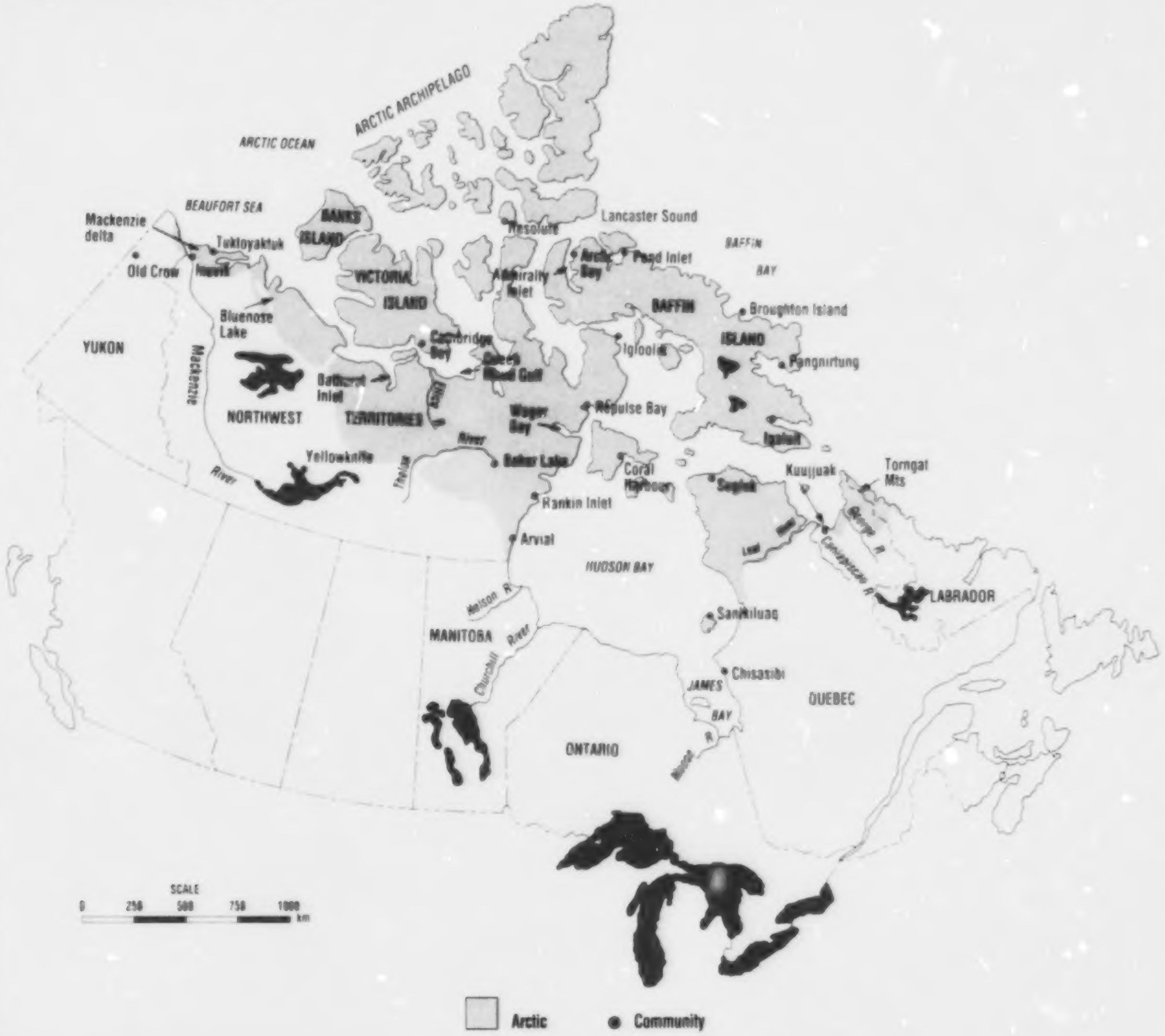
Terrestrial and marine environments

The land area of Canada's Arctic can be divided into zones, the characteristics of which are determined by general climatic conditions and physical processes (see Chapter 5). Most of the Canadian Arctic consists of a vast area of lowland, whose rather monotonous terrain of mainly shallow soils and exposed bedrock is dotted in the southern two-thirds of the region with numerous shallow lakes, the legacy of four glacial periods. In the eastern and far northeastern arctic islands, much of the terrain is mountainous, with coastlines commonly indented by steep-sided fjords that extend far inland and often terminate in massive walls of glacial ice where icebergs are calved.

The marine environment is dominated by the Arctic Ocean, which is covered for most of the year by a 2.0- to 2.5-m-thick layer of ice (Environment Canada 1984). Ice cover is an excellent insulator and effectively severs the exchange of heat between the ocean and the atmosphere. Sea ice can be "landfast" (attached to the shore) or free-floating pack ice, which is almost constantly in motion, responding to the influence of wind and water currents.

FIGURE 15.1

Place names referred to in the text


ARCTIC ARCHIPELAGO
ARCTIC OCEAN
BEAUFORT SEA
Mackenzie delta
Tuktoyaktuk
Inuvik
Old Crow
BANKS ISLAND
VICTORIA ISLAND
Resolute
Lancaster Sound
BAFFIN BAY
Arctic Bay
Pond Inlet
Admiralty Inlet
BAFFIN ISLAND
Broughton Island
Pangnirtung
Iqaluit
Igloolik
Bluenose Lake
Cambridge Bay
Queen Maud Gulf
Bathurst Inlet
YUKON
Mackenzie River
NORTHWEST TERRITORIES
Ellice River
Thelon River
Yellowknife
Wager Bay
Baker Lake
Repulse Bay
Coral Harbour
Rankin Inlet
Arvial
HUDSON BAY
Kuujjuak
Torngat Mts
Leaf
George R.
Caniapiscau R.
LABRADOR
Nelson R.
MANITOBA
Churchill River
Sanikiluaq
Chisasibi
JAMES BAY
QUEBEC
ONTARIO
Moose R.
SCALE
0
250
500
750
1000
km
Arctic
Community

Leads (i.e., open water) usually freeze over within hours or days to form new ice, only to be broken, crushed, and incorporated into the overall ice.

Arctic biota

The Arctic is the least hospitable region in Canada to most varieties of plant and animal life. Because much of the Arctic emerged from beneath the ice cap only a few thousand years ago, very little of its soil is capable of supporting large or deeply rooted vegetation (Burnett *et al.* 1989). Heaths, lichens, purple saxifrage, dryas, and cottongrass are typical plants, and tree species, such as dwarf willows, are often less than 10 cm in height (Environment Canada 1986, 1989*a*).

Despite its apparently inhospitable climate, the Arctic is rich in wildlife. Characteristic species include caribou, muskox, arctic fox, arctic hare, barren-ground grizzly and polar bears, ringed, harp, harbour, and bearded seals, walrus, beluga and bowhead whales, narwhal, Rock and Willow ptarmigan, Gyrfalcon, Snowy Owl, snow geese, and arctic charr (Environment Canada 1986, 1989*a*).

Arctic biota have relatively slow reproductive and growth rates, slow sexual maturation, and long life spans. Plant and animal species diversity and biological productivity are lower than those observed in more temperate regions of Canada.

One result is that arctic biota are thought to be more vulnerable to the detrimental consequences of environmental contaminants than those of southern areas. Another characteristic of arctic biota is the simple predator–prey relationships that exist, as reflected by relatively short food chains (Odum 1971) — for example, the lichen–caribou trophic relationship in the terrestrial ecosystem and the zooplankton – arctic cod – ringed seal – polar bear food chain in the marine ecosystem.

Global interactions

Many Canadians are aware of the importance of the arctic ecosystem in their daily lives only when an "arctic front" pushes south, bringing very low temperatures to where they live. Nonetheless, the arctic ecosystem is a fundamental contributor to global processes and the balance of life on Earth. The Arctic plays a vital role in global climate, acting as a global thermostat or "heat sink," cooling the air and absorbing the heat transported north from the tropics via the global air circulation. The integrated nature of these global processes means that global climate would change if the Arctic's existing capacity to regulate temperature were to change. It also means that the rest of the world heavily influences the arctic ecosystem. Thus, organic and heavy-metal pollutants, smoke, dust, acid precipitation, radiation fallout, and warmer air are imported to the Arctic, with potentially detrimental effects (Barrie 1985). The Arctic therefore serves as an indicator not only of natural change but also of global change influenced by human activities.

Vulnerability to toxic contaminants

One of the main threats to the environmental quality of the Arctic today is the presence of toxic anthropogenic, or human-made, contaminants. Even though levels of contaminants in the Arctic are lower than those found at other latitudes, Canada's arctic ecosystem is particularly vulnerable to their effects.

One reason for this vulnerability is that contaminants persist longer in the Arctic, because degradation processes are retarded by cold temperatures and reduced ultraviolet solar radiation. Cold temperatures also tend to condense volatile organic contaminants that have been transported over long distances, so that they are deposited in the Arctic (National Research Council of Canada 1974). The cold also slows evaporation rates, which may lead to the progressive transfer into the Arctic of chlorinated organic compounds, such as PCBs, from warmer areas of the world.

Long-lived organisms at the top of arctic food chains (e.g., seals, whales, and polar bears) are more vulnerable to contaminants than animals found at other latitudes, as they have continuous or seasonally high levels of fats, where organic contaminants accumulate (Indian and Northern Affairs Canada 1990*b*). This fact contributes to the unique vulnerability of the native arctic peoples, as many northern diets are reliant on fat-rich "country foods."

PRESSURES ON THE ARCTIC ECOSYSTEM FROM HUMAN ACTIVITIES

Municipal waste disposal

Disposal of liquid and solid waste is a concern in all arctic communities and is apt to become a much greater concern as populations increase. Although the amounts of waste produced are relatively small, there exists a potential impact on the community ecosystem.

Some communities, such as Resolute, discharge raw or primary-treated sewage directly or indirectly to the aquatic environment. Others have sewage lagoons or holding ponds, but these frequently overflow, or sewage leaches into surface drainage systems (Cameron *et al.* 1982; Dusseault and Elkin 1983).

Solid waste disposal facilities in arctic communities are primitive as a result of the lack of staff and funds, climatic restrictions, and the presence of permafrost, which forces communities to dispose of their wastes on open sites. Not only do these wastes take years to degrade because of the extremely slow rate of decomposition in the arctic environment (National Research Council of Canada 1974), but virtually all of the arctic communities are coastal, resulting in the potential for leaching of contaminants to the marine environment.

In 1986 and 1987, water and sediment samples were collected from the Pangnirtung waste disposal site in the Northwest Territories to evaluate the potential health hazards to the population from toxic substances leached into the fjord. Lead, cadmium, iron, copper, and zinc present in surface waters downhill of the waste disposal site indicated the potential for metal contamination of biota in the fjord (Haertling 1989). The discovery of high levels of zinc in arctic cod at Pangnirtung substantiated this study (Muir *et al.* 1987).

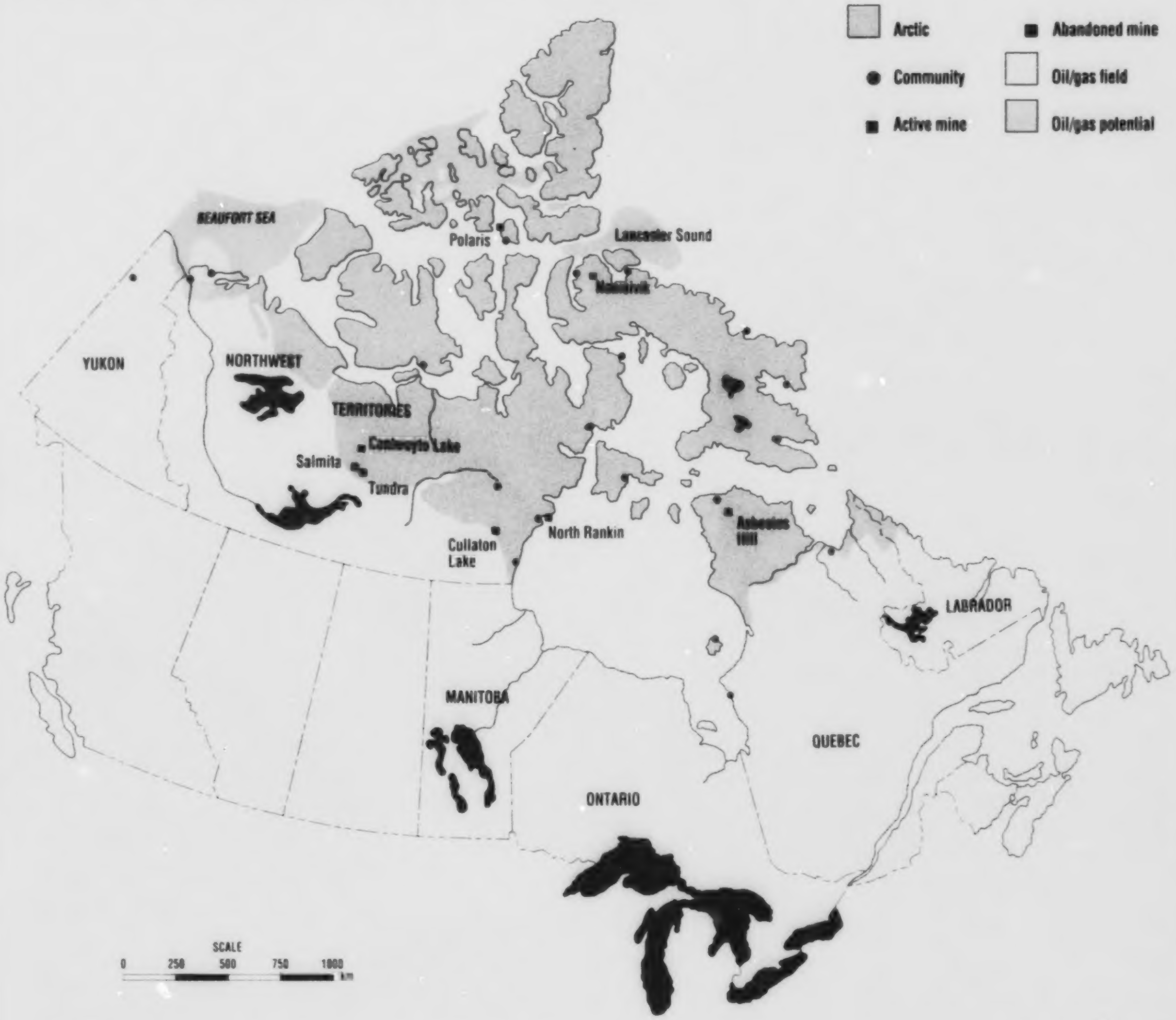
Oil and gas exploration and development

The level of hydrocarbon exploration in the Canadian Arctic has decreased since the mid-1980s as a result of relatively low oil prices, sluggish domestic markets for both oil and gas, and the relatively high cost of exploration in remote areas. Nevertheless, oil and gas exploration in the Arctic has continued in the Beaufort Sea/Mackenzie delta region (Fig. 15.2).

Drillships and artificial islands have been used to drill over 60 exploratory wells offshore in the Arctic (Canada Oil and Gas Lands Administration 1990), primarily in the Beaufort Sea. In general, the effects of point source discharges into the marine environment from offshore oil and gas drilling are localized. Elevated concentrations of mercury, lead, cadmium, zinc, chromium, nickel, and copper have been

FIGURE 15.2

Selected nonrenewable resource activities within the Arctic


▨ Arctic
● Community
■ Active mine
■ Abandoned mine
☐ Oil/gas field
▨ Oil/gas potential
BEAUFORT SEA
Polaris
Lancaster Sound
Nanisivik
YUKON
NORTHWEST
TERRITORIES
Contwoyto Lake
Salmita
Tundra
Cullaton Lake
North Rankin
Asbestos Hill
LABRADOR
MANITOBA
QUEBEC
ONTARIO
SCALE
0 250 500 750 1000 km

Source: Environment Canada (1988).

found near offshore well sites, probably originating with discharge of water-based drilling fluids, approximately 240 m^3 (1 500 barrels) of which require disposal with each exploration well (Thomas 1978; Crippen *et al.* 1980; ESL Environmental Sciences Ltd. 1982; Thomas *et al.* 1984). Depending on the distance and direction of effluent transport by ocean currents, metal levels tend to return to background values within 100 m to a few kilometres of the well site (Thomas 1978; Crippen *et al.* 1980; Mariani *et al.* 1980; Menzie *et al.* 1980; Thomas *et al.* 1984). Where oil-based drilling muds have been used, elevated hydrocarbon levels have been found in sediments 100–500 m from the well site (Erickson *et al.* 1988).

More than 300 oil and gas exploratory wells have been drilled on land in the arctic region, primarily in the western portion (Canada Oil and Gas Lands Administration 1990). It has been common practice to dispose of the waste drilling fluids associated with these well-drilling activities into sumps adjoining the oil rig. The drill wastes contain various contaminants, ranging from common metal salts to surfactants and petroleum hydrocarbons. To date, approximately 20 000 t of solids contaminated with various drilling additives and more than 250 000 L of oil and associated material have been discharged to land/sumps in the Arctic (Thomas *et al.* 1984). Accumulation of contaminants in soils and plants around the sumps tends to be extremely localized, usually confined to the area within 100 m of the sump (Smith and James 1979; Hardy and BBT Ltd. 1988).

Dredging

Dredging in the Canadian Arctic has been largely restricted to the southern Beaufort Sea and is undertaken to allow safe passage of barges, ships, and boats through navigable waters as well as to support offshore oil and gas exploration via the construction of artificial islands and underwater berms.

Between 1959 and 1985, 163 dredging operations were carried out, accounting for about 57 million cubic metres of dredged material (Sackmann *et al.* 1986). Twenty-eight artificial islands and 14 underwater berms were constructed between 1973 and 1985, using 38 million cubic metres of dredged material (Thomas *et al.* 1985; Sackmann *et al.* 1986).

The most visible impacts of dredging are localized, short-term (i.e., several hours) increases in suspended sediment concentrations in water and the destruction of benthic habitats at dredging and dumping sites (Thomas *et al.* 1985). These impacts are limited mainly to the immediate area of the dredging. Dredging is generally considered of potential concern only when long-term, cumulative effects may result from successive dredging and dumping within a relatively small area or when there is a potential for resuspension of contaminants (e.g., drilling wastes, hydrocarbons, untreated sewage) present in the dredged sediments (ESL Environmental Sciences Ltd. 1982; Thomas *et al.* 1985; Martin *et al.* 1986). Such concerns have been raised in relation to large-scale development scenarios for the Beaufort Sea.

Fuel shipment and transfer

The risk of oil and gas spills is connected mainly with the transport of oil by tanker and with the operation of exploration and production wells. To service the needs of remote northern communities, there is an annual sealift of fuel and supplies, which is a source of fuel spills. Between 1972 and 1985, there were 175 accidental oil spills in the Northwest Territories, involving a total of 1.5–1.6 million litres of diesel oil, jet fuel, gasoline, and crude oil (Sackmann 1989). These totals represent offshore and shore-based spills entering marine waters from ocean-going vessels, offshore well sites, onshore areas where petroleum is stored in tanks, and other shore-based facilities.

In 1988, a spill of 140 000 L of fuel oil occurred at the Department of National Defence site at Sugluk, even though the tanks were diked (Rowell 1990). Most of the spills that have occurred at Tuktoyaktuk and Iqaluit have resulted in elevated hydrocarbon levels in local marine environments. In Tuktoyaktuk Harbour, located 35 km east of the Mackenzie delta on the Beaufort Sea coast, elevated concentrations of petroleum hydrocarbons are apparent in sediment (paraffin, 4 400 – 31 000 ppb; PAHs, 160 – 2 600 ppb), and uptake of these substances is suspected to contribute to liver lesions and degenerative liver cells found in arctic and starry flounder fish species that are harvested but not eaten by residents of the communities (Thomas 1988).

At present, technology for cleaning up oil spills is not adequate to remove oil from ice-covered waters, and there is the potential for a major environmental disaster within arctic waters if oil and gas activity in the area and tanker size increase. An oil spill would be much more persistent in arctic waters, particularly if they were ice-covered, than in mid-latitude waters. Oil degrades more slowly in cold water (10–25 times more slowly at 5°C than at 25°C), and ice cover reduces the spreading and evaporation of the oil (spreading is two-thirds faster in the absence of ice); thus, biota and their habitat may be exposed to oil for longer periods than in temperate waters (National Research Council of Canada 1974).

In terms of potential biological effects, the short-term exposure of animals to oil in the water column is considered most significant (Baffin Island Oil Spill [BIOS] Project 1987). Certain species of waterfowl could face serious population depletion if a spill happened on their arctic breeding grounds at the wrong time.

Ocean dumping

Since 1975, 37 ocean dumping permits have been issued for the Arctic, authorizing oil spill experiments and the disposal of dredge spoils, scrap metal, and freeze-accelerating additives used in construction of ice islands (Packman and Shearer 1988). As there are no immediate solutions to the problem of the land-based waste disposal of scrap metals accumulated from communities and oil and gas operations, it is often cheaper to dump equipment and supplies into the ocean rather than haul them to other locations for reuse. The disadvantages of ocean disposal are the discharge of floating debris and the release of toxic substances into the marine ecosystem, both of which result in water pollution.

Mining

To date, only a small number of mineral prospects in the Arctic have been evaluated, and only a portion of those have been brought into production. As of 1988, Polaris and Nanisivik (lead and zinc) and Contwoyto Lake (gold) are in production, although future economic conditions may reopen some mine sites that are not viable at present (Energy, Mines and Resources Canada 1989) (see Fig. 15.2).

The main impacts of mining on terrestrial ecosystems are usually habitat losses associated with the construction and operation of the mine and its access roads. Access roads can also cause permafrost degradation and sediment inputs from runoff to adjacent aquatic habitats (National Research Council of Canada 1974). These effects are generally small and confined to local areas, and there is no evidence at present that mining in the Arctic has significantly affected critical habitats of any species.

The potential for metal contamination around sites where base metals are mined and milled results from the weathering of waste rock and rock exposed during the mining activities and accidental spillage of ore concentrates to the environment. Exposure of iron pyrite and other sulphidic minerals to atmospheric oxygen in the presence of moisture leads to one of the most acidic of all known weathering reactions (Thomas *et al.*, in press) and results in the continual dissolving of mine wastes, or tailings, and a potential long-term source of metals to the environment, where they can be taken up in food chains.

To date, many thousands of tonnes of tailings have been produced at mine sites in the Arctic (Indian and Northern Affairs Canada 1987). Although mine tailings are often a source of environmental contamination, little is known about what problems may exist today at several abandoned mines, such as the North Rankin (nickel, copper, platinum, palladium), Salmita, Tundra, and Cullaton Lake (gold), and Asbestos Hill (asbestos) mines. The active Polaris and Nanisivik mines both discharge tailings into small lakes that, during the open water season, overflow into the ocean. Concentrations of lead, zinc, cadmium, and arsenic in ocean sediments near the Nanisivik mine are higher than predevelopment levels (Arctic Laboratories Ltd. 1986), and relatively high metal concentrations have been reported in biota of various trophic levels in Strathcona Sound near Nanisivik (Wagemann 1989). Mean lead concentrations in clams rose by 1.09 ppm, representing a twofold increase over the preoperational value. Mean zinc concentrations in sea urchins and clams rose by 213 and 283 ppm, respectively, equivalent to elevations of 4.3 and 3.7 times preoperational levels (Packman and Shearer 1988) and exceeding recommended levels for lead and zinc in marine animal products intended for human consumption, as established by Health and Welfare Canada (Prakash *et al.* 1971). The ecological significance of these elevated trace metal levels in Strathcona Sound biota remains unknown, as do the impacts of the Polaris mine on adjacent marine areas.

Wastes at abandoned sites

Prior to 1972, there were no rules or regulations governing land use in the Arctic. Government and industry brought in equipment and materials that were needed to accomplish their work, then left behind what they felt was too expensive to remove. This has resulted in wastes being scattered throughout the Arctic, including abandoned buildings, electrical and other equipment (some containing PCBs), chemicals, fuels, fuel drums, and garbage. Some of the wastes are known to be hazardous or to cause hazardous conditions.

There are also hundreds of fuel caches in the Arctic, containing from one to thousands of empty drums. For example, the community of Coral Harbour on Southampton Island in Hudson Bay, which has served as a refuelling depot since World War II, is littered with an estimated 300 000 empty fuel drums (Indian and Northern Affairs Canada 1991).

During the 1950s, 42 Distant Early Warning (DEW) Line stations were constructed across the Canadian Arctic (Stanley Associates Engineering Ltd. 1986). From 1963 to 1965, 21 DEW Line stations were taken out of service due to changes in technology. These stations were abandoned "as is," in accordance with the practices at that time. In 1985, when it was realized that some of the materials at these abandoned sites were hazardous, the government undertook the removal of the wastes (Holtz and Sharpe 1986). Approximately 7 200 kg of PCB-contaminated liquid were removed (Stanley Associates Engineering Ltd. 1986). Considerable nonhazardous wastes remain at these sites, including buildings, towers, vehicles, fuel drums, and general debris.

The remaining 21 DEW Line stations are still in operation but are being phased out as part of the North American Air Defence Modernization (NAADM) project. Cleanup of the sites will be undertaken by the departments of Indian Affairs and Northern Development and National Defence and the United States Air Force.

Abandoned DEW Line and military stations are only a few of the hundreds of known waste sites across the Arctic.

Underwater noise

Concerns have been raised, particularly by native hunters of wildlife, about the potential negative effect noise may have on wildlife behaviour. Although most of the reactions are not well understood, biologists are concerned that noise from human activities, such as marine traffic, aircraft overflights, and oil and gas drilling on artificial islands, may interfere with echolocation, communication, and the normal behaviour of marine mammals in the immediate vicinity (Finley *et al.* 1984; Miller and Davis 1984; Richardson *et al.* 1985).

Although moving sources of noise, notably boats and aircraft, may cause short-term behavioural reactions and temporary displacement of various marine mammals (Finley *et al.* 1984; Miller and Davis 1984; Richardson *et al.* 1985), research directed at bowhead whales has not demonstrated a correlation between industrial activities and annual distribution problems (LGL Ltd. 1986). Notwithstanding the lack of direct evidence of serious consequences from noise disturbance, native hunters from Canada and Greenland are concerned that avoidance responses by beluga and perhaps narwhal could affect their movement into traditional harvest areas and thereby decrease hunting success.

Noise disturbance is not only a problem in underwater ecosystems; on land, it has had negative effects, even including deaths. Aircraft overflights of seals and walrus at haul-out sites can cause mortality through stampedes and abandonment of young (External Affairs Canada 1991). Labrador Inuit have

BOX 15.1

Local economies: Inuit reliance on wildlife

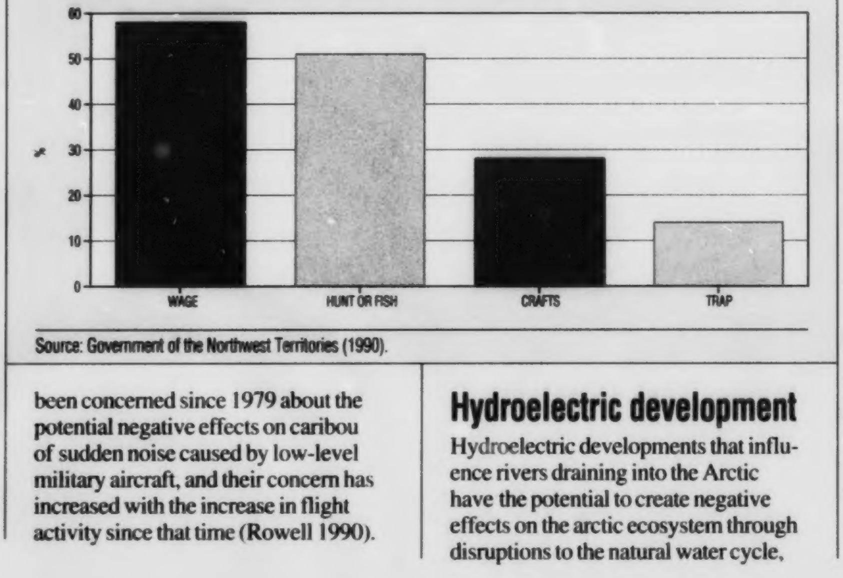
Traditional Inuit reliance on wildlife persists in the Canadian Arctic today, despite changes brought on by contact with European and Western cultures. Northern natives consume more country foods than most Canadian residents; about 80% of Inuit hunt, fish, or trap caribou, fish, marine mammals, and other basic foods (Fig. 15.B1). Subsistence hunting is only one of many wildlife-based activities engaged in by northern residents, largely outside of the money economy.

Native communities in the Arctic have tripled in population over the last 25 years (Government of the Northwest Territories 1990), and the numbers engaging in this type of resource-based activity are rising accordingly. Besides the harvesting of wildlife for food, other wildlife-based activities include the processing and sale of country food, the procurement of raw resources for the arts and crafts industry, and the making of clothing for domestic use and sale. This domestic use by the Inuit of local resources means that expensive goods do not have to be imported from southern Canada. The economic value of this domestic activity is now recognized by some economic analysts. Informal domestic activity based on wildlife accounts for 10% of the total labour income in the Northwest Territories (Usher and Weihs 1989).

The outpost camp program in the Northwest Territories and the wildlife harvester program, which is part of the James Bay Land Claims Agreement in Quebec, are examples of income supplement programs enabling natives to pursue their traditional hunting activities. Other initiatives, such as the community freezers and cottage meat processing plants for sales within the region, sponsored by the Hunters and Trappers Association of the Baffin region, are also providing useful support to Inuit communities. Soapstone and whalebone carving has also been successful, as have commercial fisheries, such as the Baffin Qikiqtaaluk and northern Quebec Makivik corporations.

FIGURE 15.B1

Inuit involved in wage employment and traditional activities for more than four weeks per year in the Northwest Territories



Source: Government of the Northwest Territories (1990).

been concerned since 1979 about the potential negative effects on caribou of sudden noise caused by low-level military aircraft, and their concern has increased with the increase in flight activity since that time (Rowell 1990).

Hydroelectric development

Hydroelectric developments that influence rivers draining into the Arctic have the potential to create negative effects on the arctic ecosystem through disruptions to the natural water cycle, impoundment of lakes causing periodic flooding, heavy erosion, and changes in the flow rate of rivers. Of particular concern are the cumulative negative effects that the expansion of the James Bay power development in northern Quebec (see Chapter 12), the expansion of the Moose River basin development in northern Ontario, and the Nelson and Churchill development in northern Manitoba will have on the marine ecosystem of Hudson Bay (F. Quinn, Environment Canada, personal communication).

Hunting

Native residents of the Canadian Arctic hunt, fish, and trap a variety of wildlife species for consumptive purposes (Wong 1985*a*) (see Box 15.1). Increased hunting pressure on some wildlife populations is a significant area of concern in many parts of the region where industrial development or local expansions of transportation infrastructure provide greater access to wilderness areas.

Contaminants from distant sources

Although levels of contaminants in the Canadian Arctic are low relative to those in populated urban areas in southern latitudes, they are much higher than would be expected from local sources alone. Soot, acid rain, PCBs, pesticides, heavy metals, and other contaminants with origins in industrialized regions of Europe, Asia, and North America are appearing in the Arctic, thousands of kilometres from their sources, and the long-range transport of contaminants is increasingly being viewed as the most significant threat to the environmental quality of the Arctic.

The composition and geographic distribution of these contaminants indicate that they are transported to the Arctic primarily by air currents. However, ocean currents and north-flowing rivers also connect the arctic ecosystem to industrialized regions of the world (Mackay and Loken 1974) (Fig. 15.3).

Chlorinated organic compounds

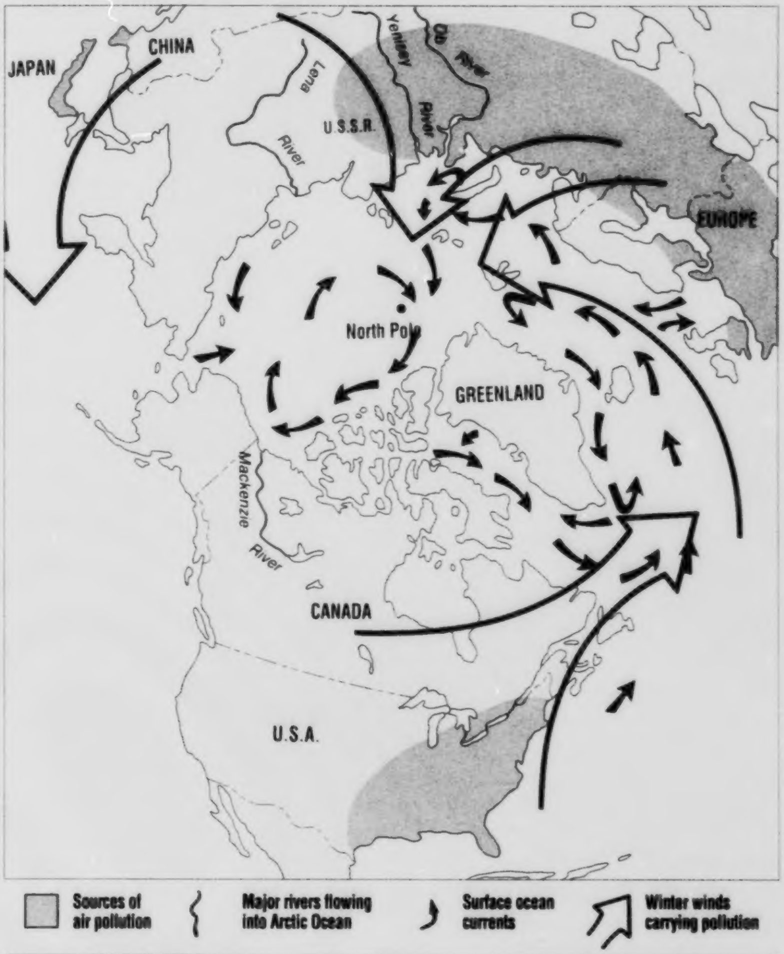
The large class of chemicals known as chlorinated organic compounds includes the industrial chemicals PCBs and HCB, the agricultural chemicals HCH, DDT/DDE, chlordane, and toxaphene, and by-products of anthropogenic activities, such as dioxins and furans. Although concentrations of chlorinated organic contaminants are generally lower in the Arctic than in heavily polluted areas such as the Great Lakes or the Baltic Sea, the more volatile compounds, such as HCB and toxaphene, are often detected in the Arctic in concentrations similar to those in source regions (Indian and Northern Affairs Canada 1990*b*).

Although trend data on most chlorinated organic contaminants in the Arctic are limited, particularly within the terrestrial ecosystem, levels of PCBs in the arctic marine ecosystem are relatively well documented (Table 15.1). The most common chlorinated organic compound detected is HCH, and the most abundant in the marine ecosystem are toxaphene, chlordane, and PCBs. Levels of DDT, HCH, and chlordane in animal species of the Northwest Territories are shown in Table 15.2.

Little is known about the potential effects of chlorinated organic compounds on ecosystem health. Although the effects of PCB accumulation on animals resident to the Canadian Arctic have not been measured, effects of PCB accumulation on animals from other areas include reproductive failure in captive seals fed North Sea fish (Reijnders 1986) and in mink fed Great Lakes fish (Aulerich and Ringer 1977) and possible reproductive failure in Baltic Sea ringed seals (Bergman *et al.* 1981), North Sea harbour seals (Reijnders 1980), and St. Lawrence River beluga (Martineau *et al.* 1987). DDT and DDE have been shown to cause egg shell thinning in birds and reduced egg viability in fish, and other chlorinated organic compounds have been linked to cancer in various animals (National Research Council of Canada 1974; Twitchell 1991).

FIGURE 15.3

Transport of pollutants into the Arctic



Source: Twitchell (1991).

Radionuclides

The primary long-lived fission products that have entered the arctic ecosystem in significant amounts, primarily as a result of atmospheric fallout from the nuclear weapons testing that took place between 1952 and 1978 and the accident at the Chernobyl nuclear power plant in 1986, are strontium-90 (half-life of 28.1 years) and cesium-137 (half-life of 30.1 years). Other radioactive threats to the arctic environment are accidents connected to the activities of nuclear-powered vessels and satellites, such as Cosmos 954, which crash-landed in 1978 near the Thelon River in the Northwest Territories (Thomas *et al.*, in press).

Because of their potential carcinogenic effects on human health, many studies have been completed since the early 1960s on the fate of these long-lived fission products. Although the cesium-137 data base for animals is not large, what data exist indicate relatively low levels of radiation (Tables 15.3 and 15.4).

Average radioactivity in air and average annual fallout of radioactivity in the Arctic have both decreased steadily since the 1963 moratorium on weapons testing (Indian and Northern Affairs Canada 1990*a*) (Fig. 15.4). Even

TABLE 15.1

Distribution of chlorinated organic compounds in the arctic ecosystem

	Marine ecosystem	Freshwater ecosystem	Terrestrial ecosystem
Pathway	•atmosphere	•atmosphere and surface drainage	•atmosphere
Data base	•limited, insufficient data to predict temporal or geographic trends accurately	•insufficient data to predict temporal or geographic trends accurately	•very limited
Levels	•toxaphene is the major contaminant in marine fish and invertebrates (Indian and Northern Affairs Canada 1990*b*) •chlordane, HCH, and toxaphene form major proportion of total load in fish from eastern Arctic (Muir 1985) •levels in arctic fish species generally low: DDT, 0.002–0.008 ppm, wet weight; PCBs, < 0.001–0.008 ppm, wet weight (Wong 1985*a*) •chlordane and PCBs major contaminants in polar bear (Indian and Northern Affairs Canada 1990*b*) •highest levels of chlordane (0.81 ppm, wet weight) and dieldrin (0.63 ppm) reported to date in blubber of beluga whales from Repulse Bay (Wong 1985*a*) •highest level of HCH residues in ringed seal blubber from Resolute and Admiralty Inlet (0.21–0.28 ppm) (Wong 1985*a*) •similar levels of chlordane and DDT in seals, zooplankton, and amphipods (Indian and Northern Affairs Canada 1990*b*) •TCDD highest in polar bear and ringed seal (of marine mammals) (Indian and Northern Affairs Canada 1990*b*) •DDE and PCB concentrations highest in eggs and fatty tissues of birds that feed primarily on fish and invertebrates (Wong 1985*b*)	•HCH most abundant chemical in fresh water (Wong 1985*a*) •toxaphene, PCBs, and chlordane highest in fish (Langlois 1987; Lockhart *et al.*, in press) •toxaphene levels in burbot 0.9–1.1 ppm, and PCB levels 0.3–0.5 ppm (Langlois 1987; Lockhart *et al.*, in press) •DDE and PCB concentrations highest in eggs and fatty tissues of birds that feed primarily on fish and invertebrates (Wong 1985*b*) •generally low levels (0.008 ppm) of DDT and PCBs in fish (Wong 1985*a*) •arctic charr at Cambridge Bay contained 10 ppm PCBs in 1984 (Wong 1985*a*)	•most abundant contaminant is HCB, followed by HCH, then PCBs, chlordane, DDT, dieldrin, and mirex (Clausen and Berg 1975; Thomas and Hamilton 1987; Muir *et al.* 1988*b*) •concentrations of contaminants lower in terrestrial animals than in marine animals by factor of 10–100 for HCH and factor of 100–1 000 for PCBs, chlordane, and DDT (Indian and Northern Affairs Canada 1990*b*) •levels of HCB in Baffin Island caribou 25–84 ppb; HCH, 7–42 ppb; PCBs, 11–52 ppb (Thomas and Hamilton 1987; Muir *et al.* 1989; Thomas *et al.*, in press)
Temporal trends	•threefold decline in concentrations of PCBs and DDT in high-arctic ringed seals and seabird eggs from early to mid-1980s (Addison and Smith 1974; Nettleship and Peakall 1987; Muir *et al.* 1988*b*) •PCBs and other organochlorine residues in polar bear and beluga in Hudson Bay increased since the mid- to late 1960s (Norstrom *et al.* 1988; Muir *et al.* 1989) •no difference in DDT residues in polar bear from 1969 to 1984 (Norstrom *et al.* 1985) •four- to fivefold increase in chlordane in polar bear over last 13 years (Wong 1985*a*)	• no information	• no information
Spatial trends	•HCH, PCBs, DDT, and DDE in all areas of marine ecosystem (Indian and Northern Affairs Canada 1990*b*) •dioxins and furans detected in a number of locations in polar bear and seal (Indian and Northern Affairs Canada 1990*b*) •toxaphene in arctic charr increased from high Arctic to Hudson Bay, indicating airborne source from south/central North America (Norstrom *et al.* 1988) •PCBs, chlordane, DDT, and dieldrin 3–4 times higher in polar bear from Hudson Bay than from Beaufort Sea (Norstrom *et al.* 1985) •2,3,7,8-TCDD and 2,3,7,8-TCDF in polar bear and ringed seal highest in the high Arctic and lowest in south, indicating source outside North America (Muir *et al.* 1989) •concentrations of PCBs and DDT in Arctic Ocean marine fish 2–5 times lower than in other northern oceans (Muir *et al.* 1989) •HCH concentrations in arctic cod similar to those in mid-latitude species (Government of Canada 1991) •PCB concentrations 25 times lower in arctic beluga than in St. Lawrence estuary beluga (Martineau *et al.* 1987; Muir *et al.* 1988*b*)	•contaminants widely distributed in fish in arctic rivers (Indian and Northern Affairs Canada 1990*b*) •toxaphene concentrations in burbot from Mackenzie River similar to those in northwestern Ontario fish, and levels in arctic charr 10 times lower than in Lake Superior lake trout (Government of Canada 1991) •PCB and DDT levels in charr 10–20 times lower than in salmon from other arctic regions (Lockhart *et al.*, in press)	•no information

though arctic regions have received 25–50% of the radioactive deposition measured in temperate regions (Feely *et al.* 1978), their relatively ineffective natural dissipative processes — resulting from very slow biological turnover rates, due to, for example, very short growing seasons and limited supplies of heat energy, nutrients, and moisture — have not cleansed their ecosystems of deposition as substantially as those in southern Canada (Svoboda and Taylor 1979; Hutchison-Benson *et al.* 1985; Taylor *et al.* 1985).

TABLE 15.2

Concentrations of selected chlorinated organic compounds in animals of the Northwest Territories

Species	Total DDT (ppb)	Total HCH (ppb)	Total chlordane (ppb)
Caribou	1–4	1–42	0.2–8
Arctic hare	< 0.2–0.9	1–50	0.6–4
Ptarmigan	0.3–11	0.4–53	0.2–7.4
Marine fish	3–21	2–110	1–44
Seabirds	3–13 000	5–10	7–230
Polar bear	10–1 200	300–870	1 800–7 000
Seal	2–4 900	1–270	2–4 600
Whale	320–800	150–240	30–2 300

Note: Total DDT means DDT and its breakdown products (e.g., DDE and DDD).
Total HCH and total chlordane also include breakdown products.
Source: Thomas and Hamilton (1987); Muir *et al.* (1988*b*).

Heavy metals

Heavy metals that bioaccumulate in biota include mercury, cadmium, lead, and arsenic. The presence of heavy metals in the arctic ecosystem is a consequence not only of long-range transport but also of natural processes and local discharges to the environment.

Except for the large data base on mercury levels in the marine ecosystem, especially in polar bear, data on heavy metal concentrations are much more limited than those for chlorinated organic compounds, and their interpretation is complicated, as it is impossible to differentiate between background and human-caused heavy-metal concentrations (Wong 1985*a*). Some general trends in the arctic marine ecosystem are apparent, although, with the possible exception of lead and mercury, the existing data base is too limited and unsystematic to provide much information on spatial or temporal trends (Table 15.5). In general, most heavy metals have increased in concentration in the Arctic (Muir *et al.*, in press), particularly lead (Settle and Patterson 1980). High cadmium and mercury levels have been found in arctic marine mammals (mainly associated with kidney and liver). For example, cadmium levels in narwhal kidney averaged 63.5 ppm, which is among the highest ever reported for marine mammals (Wagemann *et al.* 1983).

In terms of potential effects on human health, the downstream transfer of

TABLE 15.3

Distribution of radionuclides in the arctic ecosystem

	Marine ecosystem	Freshwater ecosystem	Terrestrial ecosystem
Pathway	•advection via ocean currents from the surfaces of the Atlantic Ocean and Bering Sea	•atmosphere via precipitation, bank erosion, and leaching	•atmosphere via precipitation, as well as naturally present
Data base	•limited	•limited	•not large
Levels	•cesium-137 levels near North Pole in 1979 were 24 Bq/kg (Muir *et al.*, in press)	•some local elevations near former mine sites (Thomas *et al.*, in press)	•relatively low •milk of caribou from Arviat found to contain highest concentrations of cesium-137 and strontium-90 of all wild animals surveyed (Wong 1985*a*)
Temporal trends	•concentrations have decreased steadily since 1963 moratorium on weapons testing (Indian and Northern Affairs Canada 1990*b*)	•concentrations have decreased steadily since 1963 moratorium on weapons testing (Indian and Northern Affairs Canada 1990*b*)	•concentrations decreased appreciably over past two decades, generally below 300 Bq/kg (Taylor *et al.* 1988)
Spatial trends	•no information	•widespread	•highest burden of cesium-137 occurred between 60 and 70° N in prime caribou habitat (Hutchison-Benson *et al.* 1985) •levels of cesium-137 in caribou ranged from 51 Bq/kg in Cambridge Bay caribou to 1 100 Bq/kg in George River (Quebec) caribou in 1986 (Taylor *et al.* 1988) •levels of cesium-137 in Scandinavian reindeer 30 000 Bq/kg after Chernobyl nuclear accident (Thomas *et al.*, in press)

TABLE 15.4

Mean cesium-137 concentrations in caribou muscle tissue for the main caribou herds in the Canadian Arctic

Region	Herd	Location	Concentration (Bq/kg wet tissue) 1962–66	1986–88
Western Arctic	Bathurst	Yellowknife	2 000	450
	Bluenose	Inuvik	800	140
	Porcupine	Mackenzie delta	800	40
		Eagle Plains (U.S.A.)	–	50
		Old Crow	500	–
		Arctic Village (U.S.A.)	–	130
Eastern Arctic and the islands	Baffin	Pond Inlet	400	40
		Iqaluit	–	290
	Beverly	Tent Lake	1 000	320
	Kaminuriak	Baker Lake	–	220
		Rankin Inlet	2 000	210
		Arviat	2 000	350
	Melville	Repulse	2 000	350
	Victoria I.	Cambridge Bay	–	45
	Southampton I.	Coral Harbour	–	170
	Belcher Is.	Sanikiluaq	–	55
Quebec and Labrador	George River	Caniapiscau River	–	740
		George River	–	280
		Kuujjuak	–	10
		Leaf River	–	520

Source: Thomas *et al.* (in press).

methylmercury when land floods behind hydro dams is of particular interest, as it contaminates rivers draining into the arctic ecosystem, enters the arctic food chain, and ultimately affects its people (Wagemann *et al.* 1988).

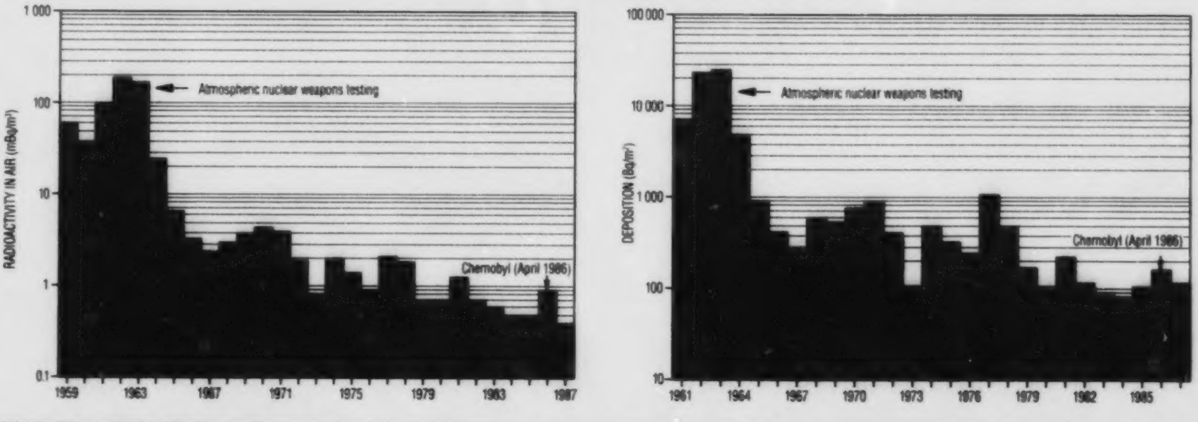
Acidic deposition

Of all the problems associated with the long-range transport of atmospheric pollutants, the best known and among the most serious is acidic deposition or acid rain, which results primarily from the reaction of sulphur and nitrogen oxides emitted by most combustion sources with water vapour (see Chapter 24). About 96% of the sulphur input to the Arctic in 1979–80 was estimated to have originated during the winter months, when air currents are more favourable for long-range transport from the industrial centres of Eurasia (Barrie *et al.*, in press). Although sulphate deposition from acid precipitation is less than 3 kg/ha (Statistics Canada 1991) and acid levels are 10–20 times lower than those found in high-impact areas farther south in eastern Canada (Indian and Northern Affairs Canada 1991), a continuous excessive acid load on the arctic ecosystem can lead to the gradual mobilization of toxic or harmful substances such as heavy metals. During the winter, acids can accumulate in the snowpack (see Chapter 24); when released in the spring, these acids can pose a threat to freshwater ecosystems, affecting the food chain and possibly human health.

Canada, the United States, and the Soviet Union agreed in principle in 1985 to reduce sulphur dioxide emissions by 30%; by 1994, Canada is committed to reducing its domestic emissions to 50% of 1980 levels (Government of Canada 1990).

FIGURE 15.4

Average radioactivity in air and average annual deposition of radioactivity in the Canadian Arctic



Source: Health and Welfare Canada (1988).

TABLE 15.5

Distribution of heavy metals in the arctic ecosystem

	Marine ecosystem	Freshwater ecosystem	Terrestrial ecosystem
Pathway	•atmosphere via precipitation	•atmosphere via precipitation, also naturally occurring	•atmosphere via precipitation, also naturally occurring
Data base	•large data base, especially for mercury	•large data base, especially for mercury	•limited
Levels	•mean cadmium levels in narwhal in Baffin Bay 63.5 ppm (Wagemann *et al.* 1983), near critical limit (Monitoring and Assessment Research Centre 1980) and among highest in world •high levels of lead (24 ppm) and zinc (280 ppm) in sea urchins near Nanisivik mine (Fallis 1982) •high mercury levels in Victoria Island bearded seals in 1973: 143 ppm compared with 26 ppm in Hudson Bay seals (Wong 1985*a*) •high mercury concentrations found in sculpins from Tuktoyaktuk and Strathcona Sound (0.18–0.21 ppm, wet weight) (Muir 1985) •selenium detected in Pacific herring from Tuktoyaktuk (3.26 ppm) and sculpins from Strathcona Sound (4.78 ppm, wet weight) (Wong 1985*a*)	•mercury levels in fish up to about 3 ppm (Wong 1985*a*) •lake trout in Ellice River contain mean mercury level of 4 ppm (Wong 1985*a*) •local elevations of arsenic in arctic waters near some mining operations (Indian and Northern Affairs Canada 1990*b*) •arctic charr in north Baffin Island contain 0.7 ppm arsenic, 2.0 ppm cadmium, and 87 ppm copper (Wong 1985*a*)	•mercury concentration in 1973 in caribou 0.2 ppm, low compared with arctic fox (0.76 ppm) and wolf (0.24 ppm) (Wong 1985*a*)
Temporal trends	•mercury concentrations in Mackenzie delta beluga lowest in 1972 and highest in 1978, coinciding with peak hydrocarbon activity (Wagemann *et al.*, in press) •lead concentrations in fossilized and present-day bivalves from Pangnirtung Fjord indicate a fivefold increase with time (Muir *et al.*, in press), consistent with the global increase following the Industrial Revolution •no indication of increase in mercury over time (Wong 1985*a*)	•no information	•no information
Spatial trends	•on global scale, mercury levels in polar bear hairs highest in Canadian Arctic and lowest in Soviet Union (Renzoni and Norstrom 1990) •mercury levels highest in western arctic polar bear and lowest in Hudson Bay polar bear (Wong 1985*a*) •mercury levels in polar bear livers showed slight decrease from Beaufort Sea to Barrow Strait (Norstrom *et al.* 1985) •mercury concentrations higher in western arctic beluga whales than in Hudson Bay specimens (Wong 1985*a*) •levels of mercury in western arctic ringed seals 10 times higher than in antarctic seals and 10 times lower than in Norwegian seals (Indian and Northern Affairs Canada 1990*b*) •bearded seal livers from Victoria Island, western Arctic, contained highest mercury burden of all marine mammals (143 ppm), considerably greater than levels in Hudson Bay bearded seals (26 ppm) (Smith and Armstrong 1978) •highest mean mercury and selenium levels in high Arctic (Wong 1985*a*) •cadmium concentrations in polar bear increased from west to east, supporting view that high levels near Baffin Island partly of natural origin (Wong 1985*a*)	•metals occur in all fresh water •levels of mercury in some arctic fish five times higher than in Great Lakes trout (Government of Canada 1991) •cadmium concentration in whitefish at Tuktoyaktuk was 40.3 ppm, 10- to 1 000-fold higher than in rest of Northwest Territories (Wong 1985*a*) •mercury trends generally higher in fish in Quebec Arctic than in landlocked fish from Northwest Territories (1–3 ppm) (Wong 1985*a*)	•no information

Arctic haze

A winter air pollution phenomenon called "arctic haze" occurs in the Canadian Arctic. This reddish-brown haze, first observed in the 1950s, is composed of very small solid or liquid particles containing a wide variety of contaminants and natural compounds, including sulphate compounds, soot and hydrocarbons, and natural materials. In winter, prevailing winds carry contaminants from industrialized regions of Eurasia into the polar region. This air mass, along with other winter weather conditions, confines the accumulating incoming pollutants to the lowermost 1 or 2 km of the atmosphere (see Chapter 2).

Although arctic pollution levels in the winter are lower than in southern urban areas, the consequences of contamination on the arctic ecosystem may be greater because of its unique vulnerability. Not only does arctic haze cause reductions in visibility in winter months as a result of a high particulate load in the atmosphere, it also increases the amount of solar radiation trapped in the troposphere. This, together with the increased blackness of the top layers of snow covering the ground, which absorbs solar radiation, can change in-going and out-going radiation and potentially modify the climate of the northern hemisphere (Hilborn and Still 1990).

Global warming

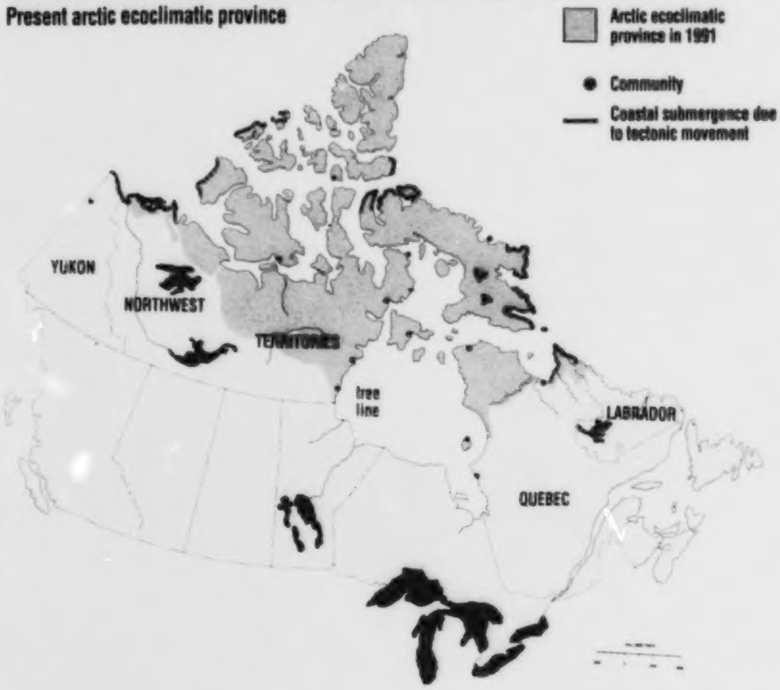
A variety of human activities, such as the burning of fossil fuels and deforestation, have increased the atmosphere's ability to retain heat by enhancing the natural greenhouse effect (see Chapter 22). Using climate models to forecast global temperature and precipitation patterns that will accompany a doubling of atmospheric concentrations of carbon dioxide, the greenhouse gas of greatest concern, scientists predict that the greatest changes will occur in high-latitude zones, especially the Arctic (Intergovernmental Panel on Climate Change 1990) (Fig. 15.5).

In the Arctic, average summer temperatures are predicted to increase only slightly, perhaps as little as 0.5°C; during winter, however, a dramatic increase in temperature is anticipated, at least twice the global average, perhaps as much as 8–10°C (Environment Canada 1989*b*). Although such temperature increases do not seem large relative to the daily or seasonal fluctuations that we accept as part of normal weather patterns, they are very large for the Arctic, where even a rise of 1.0°C in average temperature could have major impacts. During the last ice age, for example, average global temperatures were only 5–7°C cooler than today. During the last century, the average global surface temperature has increased by about 0.5°C (Intergovernmental Panel on Climate Change 1990), and there is direct evidence of warming in parts of the Arctic. Temperature profiles measured in Alaskan permafrost indicate a regional warming of 2–4°C during the same period, or at least four times the global average. Average seasonal temperatures for two 15-year periods (1959–73 and 1974–88) in the Canadian Arctic indicate no significant differences in summer, except for arctic portions of Quebec and Labrador, where the temperature increase was in the order of 0.5°C. In spring and winter, a modest cooling in the Arctic has generally prevailed (Hengeveld 1991).

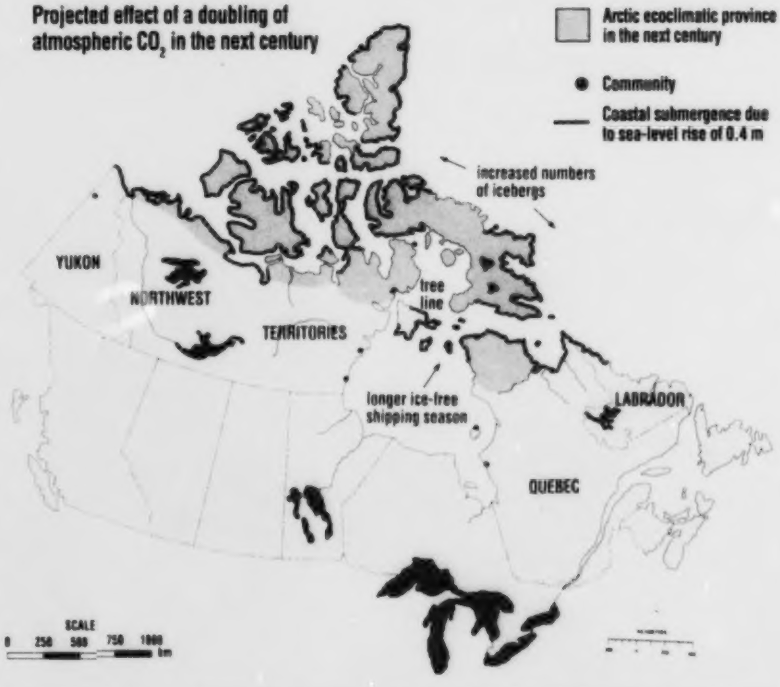
FIGURE 15.5

Some anticipated impacts of global warming on the Arctic

Present arctic ecoclimatic province


Arctic ecoclimatic province in 1991
● Community
Coastal submergence due to tectonic movement
YUKON
NORTHWEST
TERRITORIES
tree line
LABRADOR
QUEBEC

Projected effect of a doubling of atmospheric CO_2 in the next century


Arctic ecoclimatic province in the next century
● Community
Coastal submergence due to sea-level rise of 0.4 m
increased numbers of icebergs
YUKON
NORTHWEST
TERRITORIES
tree line
longer ice-free shipping season
LABRADOR
QUEBEC
SCALE
0
250
500
750
1000
km

Note: Tree line coincides with the southern boundary of the arctic ecoclimatic province.
Source: Anderson and Reid (1989); Egginton and Andrews (1989).

TABLE 15.6

Predicted impacts of global warming on the arctic ecosystem

Type of impacts	Predicted impacts
Physical	•virtually all of the terrestrial Arctic is underlain by perennially frozen ground (permafrost), some of which would melt, increasing the active layer, disrupting natural drainage patterns, and releasing methane, thus further enhancing the greenhouse effect •the tree line would gradually shift north, depending on soil conditions, by up to 750 km in the District of Keewatin at a migration rate of 100–250 km per decade, 25 times faster than under normal conditions •many regions would experience significant change in water availability as precipitation patterns change •lakes would experience a longer ice-free season of up to an additional 120 days in the fall and 15 days in the spring •thermal expansion of the oceans and melting of glacial ice could elevate mean sea level 0.5 m or more, causing beach erosion and flooding by storm surges, particularly on the Beaufort Sea coast •the extent of sea ice would diminish •coastlines would experience more fog and snow
Biological	•a northward shift of the tree line would reduce the arctic ecozone by 15–20%, such that arctic tundra vegetative communities would be restricted mainly to the arctic islands •a northward shift of the tree line would increase competition among the mainland barren-ground caribou herds for preferred calving territory, with potential negative consequences for herd populations •arctic charr and other cold-water fish species would be affected as lake temperatures increased, resulting in the northward expansion of southern fish species, such as brook trout, which compete with the current populations •ocean warming and pack ice recession may increase the range and numbers of some marine mammals, such as beluga and bowhead whales, harbour and harp seals, and walrus •polar bear and ringed and bearded seals require expanses of ice cover for breeding, feeding, and other habitat functions and may suffer population decline through pack ice recession •increased snowfall and warmer winter temperatures (mean below 0°C) would form a snow crust such that the sparse tundra vegetation would be beyond reach of caribou and muskox populations •the Arctic is a primary western hemisphere breeding and moulting ground for shorebirds and waterfowl, and their low-lying coastal habitat could be affected by permafrost degradation and sea-level rise, which would lead to saltwater intrusion •increases in the extent and duration of open water between the arctic islands would limit the movements of caribou, arctic fox, wolves, and other land animals, thereby reducing their opportunity to find suitable habitat and new sources of food
Socioeconomic	•melting permafrost could damage roads, buildings, and other human-made structures, and onshore oil and gas terrestrial development could become more difficult and expensive •fish and wildlife habitats, upon which the intensity of hunting, trapping, and fishing in an area is now largely determined by accessibility from communities, would be altered •reduction in the extent and duration of sea ice could economically benefit offshore hydrocarbon development, tourism, recreation, and marine transport, as the shipping season is expected to lengthen by six to eight weeks •the Northwest Passage could become a viable shipping route during the summer, although rougher seas, increased fog occurrence, and more icebergs may occur with changes to the marine environment •a rise in sea level would have serious implications for over half of the arctic communities, which are located on the coast essentially on flat land at or near sea level; extensive and expensive remedial protective measures would be necessary to protect them from flood damage

Source: Gates *et al.* (1986); Harrington (1986); Sheehy and Chouinard (1989); Hammar (1989); Maxwell and Barrie (1989); Egginton and Andrews (1989); Anderson and Reid (1989, 1991); Intergovernmental Panel on Climate Change (1990).

The prospect of long-term warming of the Arctic has led to intense concern over the possible physical, biological, and socioeconomic impacts that might accompany it. The most likely impacts are summarized in Table 15.6.

Although the effects of global warming would at first appear to be beneficial to the Arctic in terms of a less harsh climate and improved accessibility, the potential negative impacts described in Table 15.6 could result in the loss of the very characteristics that make the Arctic unique. The harsh climate has helped to isolate the Arctic, preserving its wildlife and allowing its native peoples and their culture to endure. By "softening" the Arctic's natural barriers, climatic warming could lead to a reduction in this isolation and jeopardize these important arctic features.

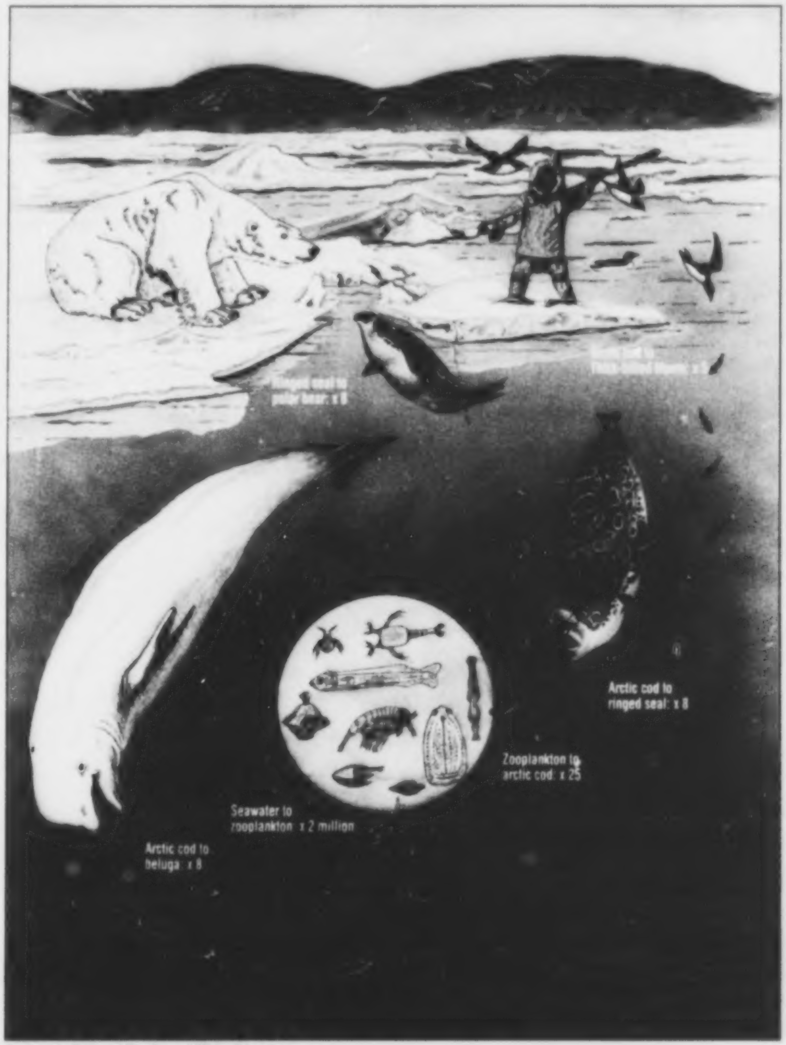
Degradation of the ozone layer

After the surprising discovery of a hole in the ozone layer over the Antarctic (see Chapter 23), it was natural to look for a similar phenomenon over the Arctic. In 1986, evidence pointed to a similar but less pronounced springtime depletion (in the range of 4–10%) of arctic ozone, the thin envelope of gas that permits the survival of life on this planet (see Chapter 23). A recent study suggests that there was a local loss of up to 50% of arctic ozone in winter 1989, which was associated with very high levels of the principal indicator of severe ozone loss — chlorine monoxide (Environment Canada 1989*c*).

Through the global circulation of air, the arctic stratosphere is receiving pollutants that are damaging the ozone layer in other parts of the world. As this phenomenon has only been recently discovered, it is poorly understood, and the implications for arctic ecosystems have yet to be clearly established.

FIGURE 15.6

Biomagnification of PCBs in the Arctic



Source: Indian and Northern Affairs Canada.

HUMAN HEALTH IMPLICATIONS

> *"We are what we eat. The Inuit used to think what they ate was okay, but now they hear that this is not true. This is of great concern."*
>
> *— Ruby Arngna'naaq, Inuit Tapirisat of Canada*

Although concentrations of contaminants are generally lower in the Arctic than in southern Canada, there is nevertheless considerable concern for their possible adverse effects on human health. This concern arises largely from the reliance of the arctic native population on "country foods" — local meat and fish that are principal sources of energy and nutrients in native diets. These foods have been shown to contain significant levels of human-made contaminants (Thomas and Hamilton 1987; Muir *et al.* 1988*a*; Thomas 1990), particularly in the fatty tissues, which tend to accumulate and retain fat-soluble contaminants such as chlorinated organic compounds. In fact, native arctic people commonly consume portions of harvested species not considered edible in Health and Welfare Canada guidelines (e.g., blubber of marine mammals) but that contain a large proportion of the contaminant load (Wong 1985*a*).

Although there is virtually no dietary information available for Inuit communities, except for a limited survey on Broughton Island in the Northwest Territories, harvest data can be used to estimate the consumption patterns of the Inuit. Human consumption of northern country foods is high on a per capita basis and is encouraged by federal and territorial governments. The average annual per capita consumption of country foods in the Keewatin, Kitikmeot, and Baffin Island regions, for example, has been estimated at 267 kg, which is more than twice the estimated national average annual consumption of meat and fish (117 kg) (Wong 1985*a*). Contamination of these country foods therefore provides a critical pathway to human consumers.

Chlorinated organic compounds

Of all the contaminants of external origin that are present in the Arctic, chlorinated organic compounds are thought to present the greatest threat to human health because of their persistence in the environment, high biomagnification, generally high inherent toxicity, widespread use, and high tendency to be stored in the fatty tissues of animals. Evaluation of the extent to which these compounds affect human health is complex and depends upon the rate and length of exposure to them and particular human characteristics that vary from individual to individual, such as age, sex, body weight, physiology, and sensitivity to contaminants (Wong 1985*a*). To date, DDT and PCBs are the only ones that have been studied for more than five years in terms of human health effects. The PCB issue, outlined below, illustrates the possible implications of chlorinated organic contaminants in the arctic food chain.

PCBs are biomagnified in food chains because of their great chemical persistence, stability in biological systems, and fat solubility (Muir *et al.* 1988*a*). PCBs in seawater biomagnify at each link in the food chain, so that the levels in marine mammal blubber in the Canadian Arctic are approximately 400 million times those in the Arctic Ocean (Fig. 15.6). This can lead to the presence of relatively high concentrations in animal tissues eaten by northerners, even when original inputs from outside the Arctic are low. The long life span of species such as polar bears and whales, coupled with a strong dependence on fat reserves within and between species, including humans, makes arctic ecosystems particularly vulnerable to the impact of this type of contamination.

To date, no acute PCB toxicity has been reported in an arctic resident. Furthermore, no attempt has been made to detect either acute toxicity or the more subtle consequences that may result from long-term ingestion of PCBs at concentrations insufficient to provoke symptoms or clinical signs. The effects of chronic dietary exposure to PCBs on the normal functions of the central nervous system and the immune system and the risk of cancer to humans are uncertain (Kinloch *et al.* 1988) (see Box 15.2). For human consumers of fish and marine mammals in the Arctic, the principal concerns are for the developing fetus and breast-fed infants, due to increased sensitivity of the developing fetus and the increased body burden per kilogram of the infant (Fein *et al.* 1984). Michigan women who consumed large amounts of PCB-contaminated Great Lakes fish (daily PCB intake exceeded 1 µg per kilogram body weight) experienced shortened gestation and gave birth to children with reduced birth weight, smaller head circumference, and compromised neuromuscular development (Fein *et al.* 1984).

Radionuclides

Radionuclides are a concern in the arctic region because natives consume caribou, which feed almost exclusively on lichens, which in turn are very effective at trapping radioactive fallout. Although concentrations of cesium-137 in caribou muscle have decreased appreciably over the past two decades, they have not disappeared (see Table 15.4) (Thomas *et al.*, in press).

Measurements of cesium-137 radioactivity in caribou meat from various arctic locations following the Chernobyl accident in April 1986 indicated that about 25% of the total cesium-137 present could be attributed to the accident. The majority of the cesium-137 radioactivity was the residual from the radioactive fallout from the atmospheric nuclear weapons testing of the 1960s. An arctic ecosystem geographically closer to the accident did not fare as well as the Canadian Arctic. Severe contamination of the forage of Scandinavian reindeer led to severe contamination of the reindeer themselves (30 000 Bq of cesium-137 per kilogram), to the extent that thousands of animals became unfit for human consumption and had to be destroyed (Thomas *et al.*, in press).

Based on an estimate of average annual per capita consumption of caribou meat in the Arctic of 100 kg, the exposure to radiation in 1986–87 from this source can be calculated as 0.1–1 mSv, depending on location. The International Commission on Radiological Protection (1979) set a dose limit for exposure of the public to radioactivity from a controlled source of 1 mSv per year over a life span of 70 years, and an annual exposure to this dose is estimated to lead to a risk of 1 in 100 000 of developing a fatal cancer in a lifetime (Johnson and Tutian 1985). Therefore, the risk of fatal cancer to an individual consuming 100 kg of caribou meat can be estimated to range from 1 in 100 000 to 1 in 1 million in arctic communities, whereas the risk of cancer in the general Canadian population due to lifestyle is 1 in 4 (National Cancer Institute of Canada 1989).

Although the cancer risk associated with the consumption of caribou meat contaminated with cesium-137 is so small as to preclude the need for humans to exclude it from their diets, it does serve to illustrate that events occurring at locations distant from the Arctic have the potential, through long-range transport mechanisms, for rapid and significant impact on the arctic ecosystem.

Mercury

Studies in 1984, in the area of the first phase of the James Bay hydroelectric project, showed that 64% of native Cree residents of Chisasibi in Quebec had unsafe levels of methylmercury (Gorrie 1990) and that fish in the same area had some of the highest levels of mercury in the world. Not only can methylmercury adversely affect the health of adults, but it can also be transferred from mother to fetus during gestation (World Health Organization 1990).

Between 1971 and 1982, Health and Welfare Canada initiated the most comprehensive survey to date of exposure of native Canadians to mercury. Mercury levels in blood and hair were monitored in residents of 350 communities across Canada (Wong 1985*a*). This study showed that mercury levels in hair of Igloolik residents were higher than those of southern populations, but no symptoms of mercury poisoning were observed. In a survey conducted by Health and Welfare Canada in 1985–87 at Broughton Island in the Northwest Territories (see Box 15.2), blood samples taken from residents were analyzed for methylmercury content. Over 58% of all samples tested were found to contain concentrations of mercury at or above the Health and Welfare Canada "concern" level of 20 ppb (Kinloch *et al.* 1988), and three individuals (1.5%), all adult males, exceeded the "at risk" level of 100 ppb. Early symptoms of methylmercury intoxication in adults have been observed at blood concentrations between 200 and 600 ppb (Clarkson *et al.* 1975). As a comparison, much higher blood methylmercury concentrations were detected in west Greenland residents, where blood mercury concentrations correlated with the amount of marine food in the diet; the exposure level was so high that clinical effects were anticipated (Hansen 1981). Dependence on country foods has increased the health risks to these residents.

Municipal wastes

Public health concerns with respect to municipal wastes may be significant in communities where resources such as shellfish are harvested from waters containing fecal coliform bacteria and where marine mammals are butchered on adjacent shorelines. The possible relationship between sewage disposal practices, consumption of contaminated meat, and the incidence of enteric diseases in humans is still unknown (Stanley and Associates and Dobrocky Seatech 1987).

MANAGEMENT OF THE ARCTIC ECOSYSTEM

Within Canada, a substantial evolution is taking place surrounding the roles of various government departments and agencies in managing the Arctic. Following the Inuvialuit Final Agreement, the Inuvialuit of the western Arctic participated actively in maintaining and preserving the arctic environment in their settlement region. As wealth and control are redistributed through present and future land claim agreements, and as responsibilities for the Arctic held by Indian and Northern Affairs Canada devolve to the territorial governments, the need for effective interagency coordination will be imperative to deal with the important environmental issues facing the Arctic into the 1990s.

This section focuses on measures that are being implemented or are being developed to address environmental concerns in the Arctic. Environment Canada (1986) noted 37 federal acts and 42 territorial/provincial acts containing environmental provisions that apply to the Arctic. At least nine federal departments and agencies as well as two territorial governments, four provinces, native agencies, and a number of special-purpose commissions and advisory boards are directly involved in the administration of northern resource and environmental protection legislation. These are principally managed and coordinated in the Arctic by Indian and Northern Affairs Canada.

BOX 15.2

Regional study: Broughton Island, Northwest Territories

To assess the possible risk to the health of arctic residents of consuming country foods containing PCBs, Health and Welfare Canada initiated a series of studies in 1985, 1986, and 1987 at Broughton Island (see Fig. 15.1). This community was chosen as the study site because harvest data indicated that it had the highest potential per capita intake of country foods among communities of the Baffin Island region (Kinloch *et al.* 1988). The studies included a comprehensive diet survey, measurement of PCB concentrations in various foods consumed, measurement of PCBs in human blood and breast milk, and an evaluation of the nutritional value of country foods.

Figure 15.B2 illustrates the consumption of various types of country foods by female and male Inuit residents. Seal, caribou, narwhal, fish, and walrus accounted for 90% or more of the country foods consumed. Figure 15.B3 shows the mean daily intake of PCBs from various country foods by residents. Of residents surveyed, 15.4% of males and 8.8% of females ingested more than the Canadian conditional tolerable daily intake (TDI) of PCBs, set by Health and Welfare Canada at 1 μg per kilogram of body weight. The TDI is the quantity of a chemical that is considered by toxicologists to be safe for human consumption every day for an entire lifetime; exceeding the TDI does not mean that an individual is in danger of suffering adverse effects related to intake of a contaminant, only that the safety margin is reduced.

The study found that PCB concentrations in blood samples exceeded the Health and Welfare Canada "tolerable" guidelines in 63% of children under 15 years of age, 39% of females aged 15–44 years, 6% of males 15 years and older, and 29% of women 45 years and older. One-quarter of the breast milk samples analyzed also exceeded the established "tolerable" PCB level, whereas the remaining samples contained PCB concentrations lower than the national average. A survey of the Inuit women in northern Quebec showed that PCB concentrations in breast milk were five times those of southern Canadian Caucasian women in the study (Dewailly *et al.* 1989). For the Inuit women, the mean monthly consumption of freshwater fish, marine mammals, and marine fish was 18, 10, and 9 meals, respectively.

Country foods are nutritionally superior to marketed (southern) foods, and substitution may lead to nutritional deficiencies and associated risks to health. There are known risks of obesity, diabetes, cardiovascular disease, and cancer associated with the transition from a country food diet to a "southern Canadian" diet. Therefore, although there may be risks to health associated with the presence of PCBs in the traditional Inuit diet, there are major benefits associated with the nutrients present. Based on current information, the benefits to Broughton Island residents of native country foods and breast feeding are greater than the risk from the PCBs in country foods or in breast milk at the observed levels (Kinloch *et al.* 1988).

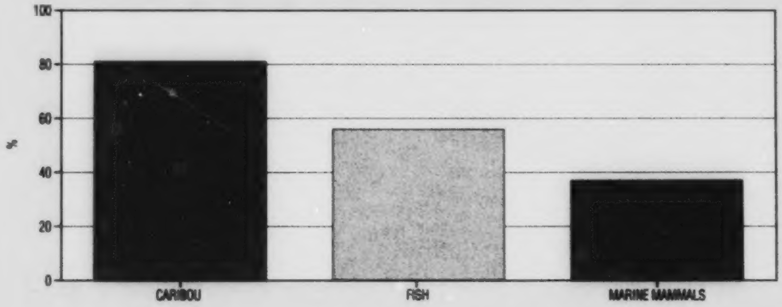
Superimposed on this legislated base are a number of government policies that influence environmental protection in the Arctic, including various national environmental and conservation strategies and several international agreements.

Arctic Environmental Strategy

The Government of Canada has identified the Arctic (Northwest Territories and Yukon) as a region needing priority action with respect to environmental and other concerns. As such, the Arctic is receiving special attention in Canada's Green Plan (Government of Canada 1990). The Arctic Environmental Strategy, an integral part of the Green Plan, was released on April 29, 1991,

FIGURE 15.82

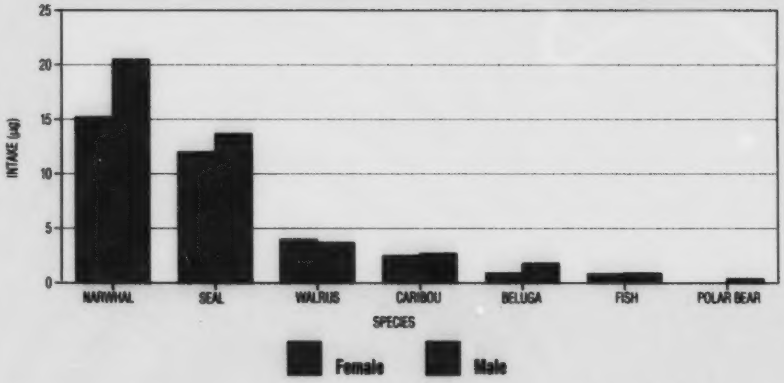
Consumption of various types of country foods by Inuit residents of the Northwest Territories



Source: Wong (1985*a*).

FIGURE 15.83

Mean daily intake of PCBs from various country foods by female and male Inuit residents of Broughton Island, Northwest Territories



Source: Kinloch *et al.* (1988).

and is an action plan to deal with environmental issues and concerns in Canada's North. Over the next six years, the government is committed to a $100-million program to set up a network of stations to monitor water pollution, to clean up hazardous and nonhazardous waste dumps (e.g., Iqaluit and Coral Harbour in the Northwest Territories), to conduct research and monitoring programs related to the long-range transport of contaminants such as PCBs and DDT to the Arctic, to determine the impacts of contaminants on the ecosystem and the risks to human health, and to ensure that environmental and economic integration is achieved by providing assistance to northern communities in meeting economic and environmental objectives (Indian and Northern Affairs Canada 1991).

The Arctic Environmental Strategy will complement other initiatives that encompass environmentally sustainable development, such as the settlement of comprehensive land claims (see Box 15.3), new and revised legislation and regulations, and the devolution of provincial-type responsibilities for natural resources to the territorial governments.

Canada's Green Plan also makes provision to document trends in the quality of the ozone layer and better define the environmental implications for arctic ecosystems. This will be achieved by setting up an arctic observatory by 1992 to contribute to a program of stratospheric research and monitoring undertaken by arctic nations.

Conservation strategies

Work is under way in the Arctic on several conservation strategies for the sustained use of arctic resources (Smith 1990) in response to recommendations of the World Commission on the Environment and Development (1987) and two Canadian task forces — the Task Force on Northern Conservation and the National Task Force on Environment and the Economy (1987). These include the federal Arctic Marine Conservation Strategy, the territorial Northwest Territories and Yukon conservation strategies, the Inuit Regional Conservation and Indigenous Survival International strategies, and the Task Force on Northern Conservation Strategy, composed of representatives from federal and territorial governments and international circumpolar aboriginal groups.

To date, some accomplishments have included the North Slope Borough–Inuvialuit Game Council polar bear management agreement and the completion of a computerized inventory of proposed and existing conservation areas for the Northwest Territories. Also under way are land claim negotiations with the Tungavik Federation of Nunavut and discussions on proposed parks on northern Baffin Island/Lancaster Sound, Banks Island, Bluenose Lake, and Wager Bay in the Northwest Territories and Torngat Mountains in Labrador (Environment Canada 1990*a*).

BOX 15.3

Comprehensive aboriginal land claims

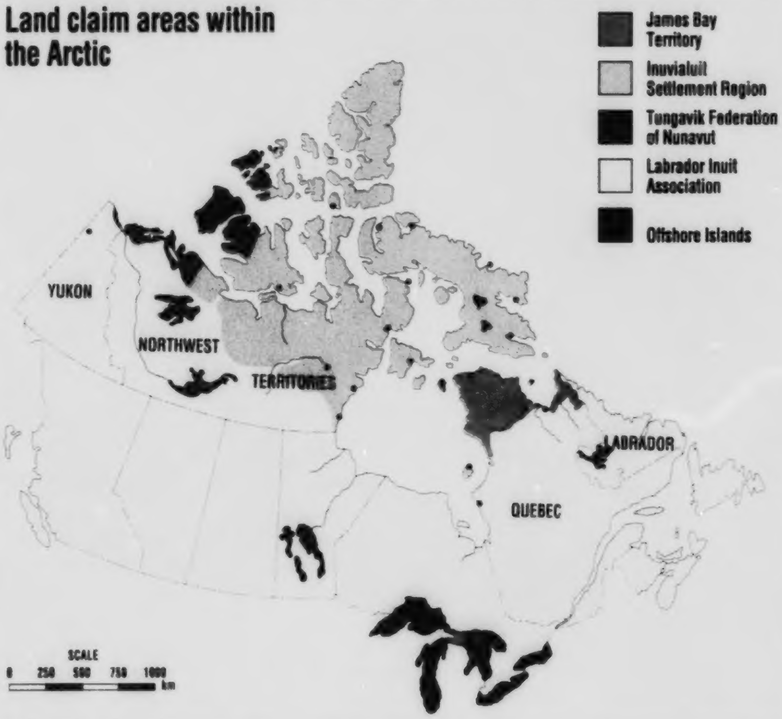
In recent years, the settlement of comprehensive aboriginal land claims in the Arctic has represented a major step towards establishing mechanisms for resolving issues and managing resources in a sustainable fashion.

The Inuit and Inuvialuit have always claimed a special relationship to the land as a basis for their cultural distinctiveness and special aboriginal status, and recognition of this relationship through the settlement of claims based upon aboriginal title is a fundamental objective of the native people. Settlement agreements are comprehensive in scope, including such elements as land title, specified hunting, fishing, and trapping rights, and financial compensation. Such claims help to clarify right to ownership, use, and management of land and resources; in so doing, the settlement agreements may contribute to meeting the demands of economic development and the cultural and social well-being of these residents (Indian and Northern Affairs Canada 1987).

Two final agreements — the Northern Quebec Final Agreement 1975 and the Inuvialuit Final Agreement 1984 — have been negotiated. An agreement in principle with the Tungavik Federation of Nunavut in the eastern Arctic was signed in 1990 (Crowe 1990), to be concluded by October of 1991. In November 1990, the Inuit of Labrador signed a framework agreement that will provide the basis for negotiation of an agreement in principle for the Labrador comprehensive claim (Fig. 15.B4).

FIGURE 15.B4

Land claim areas within the Arctic



Source: Crowe (1990).

Protected areas

Figure 15.7 illustrates areas in the Arctic that currently have legislated protective status. At present, federal and territorial legislation protects approximately 200 000 km^2 or about 8% of the arctic ecosystem (Environment Canada 1990*b*). The number of sites has almost doubled since 1970, and the sites considered highly protected (levels I and II) under the World Conservation Union (see Chapter 7) account for 4.8% of the arctic ecosystem, incorporating an area of 65 000 km^2 (Figs. 15.8 and 15.9).

Five sites in the Arctic also fall under the Convention on the Conservation of Wetlands of International Importance, or the Ramsar Convention. These sites are internationally recognized as important but have no legislative protection, although four of the five sites fall within areas of protection, such as the McConnell River, Queen Maud Gulf, and Dewey Soper migratory bird sanctuaries and the Polar Bear Pass National Wildlife Area.

Land-use planning commissions

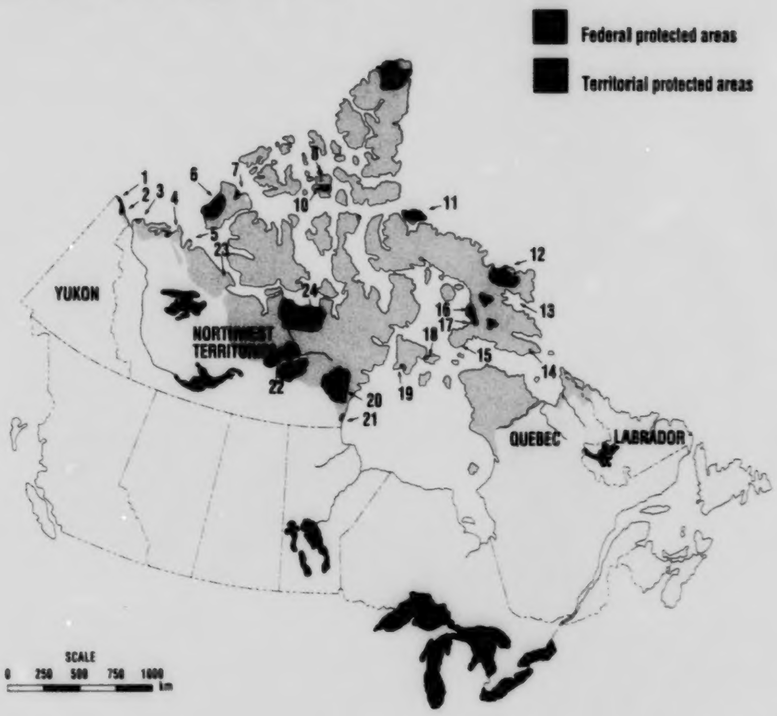
Land-use planning exercises in the Northwest Territories and Yukon have wound down and will become part of land claims agreements (see Box 15.3). Within the Arctic, the Lancaster Sound Regional Land Use Plan, the first such plan to be prepared in the Northwest Territories, has been approved by the federal and territorial governments (Lancaster Sound Regional Land Use Planning Commission 1989), and a draft plan has been completed for the Beaufort Sea/Mackenzie delta and the District of Keewatin. In Quebec, the Northern Quebec Land Use Plan for the territory north of 55°N latitude is forthcoming.

Selective harvesting

Selective harvesting of arctic animals for their meat or for their skins has been occurring for centuries. Today, harvesting of arctic animals also occurs for scientific research purposes and for trophies. To preserve the existing balance, population dynamics and ecosystem interlinkages must be understood

FIGURE 15.7

Protected areas within the Arctic



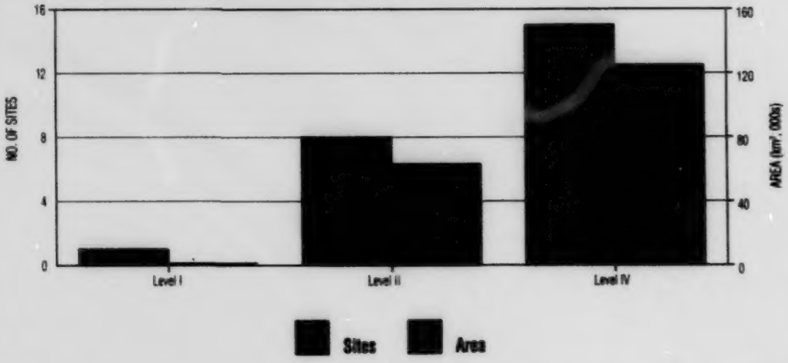
No.	Site	Status
1	Northern Yukon	National park
2	Herschel Island	Territorial park
3	Kendall Island	Migratory bird sanctuary
4	Anderson River delta	Migratory bird sanctuary
5	Cape Parry	Migratory bird sanctuary
6	Banks Island #1	Migratory bird sanctuary
7	Banks Island #2	Migratory bird sanctuary
8	Seymour Island	Migratory bird sanctuary
9	Ellesmere	National park reserve
10	Polar Bear Pass	National wildlife area (Ramsar site)
11	Bylot Island	Migratory bird sanctuary
12	Auyuittuq	National park reserve
13	Pitsutinu Tugavik	Territorial park
14	Sylvia Grinnel	Territorial park
15	Cape Dorset	Migratory bird sanctuary
16	Dewey Soper	Migratory bird sanctuary (Ramsar site)
17	Bowman Bay	Game sanctuary
18	East Bay	Migratory bird sanctuary
19	Harry Gibbons	Migratory bird sanctuary
20	Kaminuriak Herd	Caribou protective measures
21	McConnell River	Migratory bird sanctuary (Ramsar site)
22	Thelon	Game sanctuary
23	Bloody Falls	Territorial park
24	Queen Maud Gulf	Migratory bird sanctuary (Ramsar site)

Source: Environment Canada (1990*b*); Anderson and Reid (1991).

and realistic harvest quotas imposed to prevent species from becoming at risk — i.e., endangered or threatened, as recognized by the Committee on the Status of Endangered Wildlife in Canada. Such was the case of the right and bowhead whales, which were once very plentiful in the Arctic but were hunted almost to extinction in the 1800s and early 1900s. Today, endangered species include the eastern arctic population of bowhead whale, the southeast Baffin and Ungava bay populations of beluga, the eastern population of wolverine, two populations of the Peary caribou herd, and the Eskimo Curlew. Threatened species include the Eastmain population of beluga, a population of the Peary caribou herd, and the Peregrine Falcon (see Chapter 6).

FIGURE 15.8

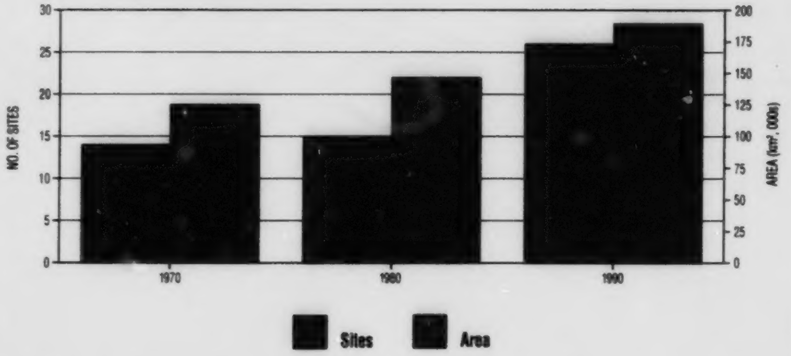
Level of protection of areas by the World Conservation Union



Source: Environment Canada (1990*b*).

FIGURE 15.[illegible]

A chronology of conservation areas



Source: Environment Canada (1990*b*).

TABLE 15.7

International agreements and conventions

Agreement	Date
Agreement to Protect Whales	1946
Convention on the Prevention of Marine Pollution by Dumping Wastes and Other Matter	1972
International Agreement on the Conservation of Polar Bears	1973
Convention for the Prevention of Pollution from Ships	1973
Convention for the Prevention of Marine Pollution from Land-based Sources	1974
United Nations Economic Commission for Europe: Convention on Long-range Transboundary Air Pollution	1979
United Nations Convention on the Law of the Sea	1982
Canada/Denmark/Greenland Marine Environmental Cooperation Agreement	1983
United Nations Environment Programme — Montreal Guidelines for Protection of the Marine Environment Against Pollution from Land-based Sources	1985
Convention for the Protection of the Ozone Layer	1986
Canada/Norway Exchange of Letters on Cooperation in Science and Technology	1986
Canada/U.S.A. Porcupine Caribou Agreement	1987
Canada/U.S.S.R. Agreement on Cooperation in the Arctic and the North	revised 1989
The Finnish Circumpolar Initiative on Protection of the Arctic Environment	1991

International agreements

Because air pollution from the industrialized regions of the world is the most important source of contaminants in the Arctic, proper management and protection of the arctic ecosystem from the effects of these contaminants require committed international cooperation. To this end, Canada is a signatory to several multilateral and bilateral agreements and conventions aimed at protecting the arctic ecosystem and its resources (Table 15.7).

CONCLUSIONS

The Arctic is generally a fairly resilient environment, its ecosystems having adapted to major seasonal and diurnal extremes in temperature and amount of sunlight. Although it has managed to retain most of its primeval wilderness quality, the Arctic is nonetheless vulnerable to the effects of pollution and other human activities within the region as well as outside it. Severe perturbation of a particular species or habitat can remove a whole level within an ecosystem that is intrinsically unstable because of relatively simple food chains, and recovery periods following disruption can reach decades or centuries.

In terms of point source pollution in the Arctic, the negative environmental impact is generally confined to the immediate vicinity of the activity. The greatest problem is waste from human activities, because of inadequate arctic disposal practices, the slower processes of biodegradation and detoxification of chemical pollutants in the arctic ecosystem, and an increasing population. As if locked in time, waste from decades ago litters beaches of some uninhabited remote arctic islands, drifting ashore from sources of northern activity. Several studies have been undertaken over the past decade to better define and solve existing waste management problems, and more environmental studies are needed. Also needed are studies that predict environmental consequences before they occur and provide a basis for averting future problems with waste.

The Arctic is a prime indicator of overall global environmental health, as trends within the Arctic of contaminants from distant sources can serve as indicators of the rate and extent to which these pollutants are entering the global environment. Long-range transport via air currents, rivers, and ocean currents is the primary pathway of contaminants to the Arctic, as opposed to local sources. However, because of the unique character of the Arctic (cool temperature, remoteness, and sparse wildlife and human populations), there are limited scientific data on levels of contaminants in the environment and their sources and pathways; hence, few data are available for long-term trend monitoring, and even less information is available on the potential effects of these contaminants on the ecosystem, including the health of the indigenous population.

The need for long-term area-wide monitoring programs is fundamental to ensuring the continued health and well-being of the arctic ecosystem. The need for sustainable development has also become crucial during the last few years. With the wealth of resources, particularly hydrocarbons and minerals, in the Arctic, it seems inevitable that many of them will be developed. It is therefore essential that they be extracted and transported to markets in ways that sustain the integrity of the arctic environment for the benefit and enjoyment of present and future generations of indigenous people and, indeed, all Canadians.

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16

COURTESY OF DAVE W SMITH CANADIAN WILDLIFE SERVICE DELTA

HIGHLIGHTS

About 1.7 million people (more than one-half the population of British Columbia) live in the lower Fraser River basin, a region that occupies less than 2% of the total area of the province.

■

Since 1986, the population of the Fraser River basin has increased by over 45 000 new residents annually. Such rapid population growth has profoundly affected the basin as natural ecosystems have been radically altered.

■

Air quality in the region is generally good, except during episodes of limited air movement. Since 1981, there has been a dramatic decline in airborne lead levels. The trend for ground-level ozone and particulate matter has generally been downward, although there has been a slight increase in ozone levels in recent years. Automobiles and other mobile sources produce nearly 85% of the air pollution.

■

Nearly all monitoring studies of the Fraser River have concluded that insufficient information exists to determine trends in water quality.

■

At least five bird species and one mammal have been extirpated from this area. Less than 1% of the basin is reserved for the use of wildlife. In the aquatic environment, fish stocks face the combined threat of habitat deterioration and declining water quality on one hand, and increased harvesting on the other.

■

The fertile lowlands in the basin are some of the most important agricultural lands and wildlife habitat in Canada. These lands have come under intense pressure for development. Rural resource lands in the greater Vancouver region have been converted to urban uses at a rate of over 600 ha annually in recent years. Since 1985, agricultural lands in the entire lower Fraser River basin have been disappearing at a rate of almost 400 ha per year.

■

About 1.27 million tonnes of solid waste are generated in the lower Fraser River basin every year. The volume of solid waste produced increased 11% between 1982 and 1988. During the same period, the volume of waste recycled increased from 6 to 10%.

■

Increased population threatens to outstrip the capacity of existing and planned solid waste systems as early as 1995, even if the goal of recycling more refuse is successfully met.

■

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> “Vancouver was then only a little town, but it was growing hard. Almost every day you saw more of her forest being pushed back, half-cleared, waiting to be drained and built upon mile upon mile of charred stumps and boggy skunk-cabbage swamp. fireweed, rank of growth, springing from the dour soil to burst into loose-hung, lush pink blossoms, dangling from red stalks, their clusters of loveliness trying to hide the hideous transition from wild to tamed land.”
>
> — Emily Carr (1946)

INTRODUCTION

In all of British Columbia, nowhere are the environmental pressures and competing demands for space and resources greater than the fertile and heavily populated lower Fraser Valley. In view of the environmental stresses that the area is already experiencing, questions must be asked: What is the present state of the environment, how has it recently changed, and what are the prospects for ensuring the environmental well-being of the lower Fraser River basin?

British Columbia has a physiography that focuses many human activities into relatively small areas. Because 90% of the province is mountainous, its population and its industries crowd into the valley bottoms and estuaries, where conditions are suitable for residential, recreational, commercial, and industrial development. Forestry, agriculture, transportation, wildlife refuges, and parks also compete for land and water in valleys and estuaries. The lower Fraser Valley epitomizes this clash of competing and often conflicting uses and bears the brunt of environmental stresses in the province.

The lower Fraser River basin extends from the coast to the Fraser Canyon, encompassing an area of 17 000 km^2 (Fig. 16.1). It can be defined by three physiographic features. Firstly, the region is bordered on the north and east by the mountains of the Coast and Cascade ranges, whose streams and lakes drain into the Fraser River. Secondly, the basin includes a broad floodplain that extends westward to the Strait of Georgia from near Hope, where the river emerges from the mountains into the Fraser lowland. The third feature is the Fraser River delta, the largest delta formation on Canada's Pacific coast, covering 590 km^2.

The basin's moderate climate and beautiful setting attract many new residents. It is by far the most densely populated and fastest growing part of British Columbia. Its 1.7 million people represent more than half the population of the province, and this number is expected to increase by nearly 600 000 over the next 20 years.

The natural resources of the lower Fraser River basin have declined markedly since European settlement. Not only have the quality of air, water, and land worsened, but the populations of native plants and animals have been reduced, and some species have been lost altogether. These components of the lower Fraser River basin ecosystem are now examined for current conditions and recent trends.

COMPONENTS OF THE LOWER FRASER RIVER BASIN ECOSYSTEM

Air

Climate in the lower Fraser River basin is dominated by the presence of two features: the Pacific Ocean and the encircling mountains. High- and low-pressure systems typically flow into the region from the ocean. Generally, summer highs produce warm, dry, settled weather with rainless periods that may last for weeks. In autumn and winter, low-pressure systems create moist, unsettled weather and cool temperatures. The highly varied terrain introduces many deviations from this general pattern, however, creating a diversity of microclimates.

Wind patterns vary daily and seasonally, also due to the influence of terrain. During summer days, sea breezes and slope wind systems frequently drive air eastwards, up the valley. Conversely, land breezes and down-valley wind systems can drive air seawards at night. Temperature inversions can trap pollutants in the valley and prevent vertical mixing in the air column, particularly in the fall and winter months. Under these conditions, stale air and pollutants may flow up and down the valley for weeks on end.

Temperatures are moderate and relatively uniform throughout the region, with a mean of 1°C in January and 17°C in July. Again, factors of terrain, altitude, and exposure result in marked variations within this general pattern, but most of the lowland areas in the basin enjoy more than 200 frost-free days per year.

Water

The Fraser carries the largest mean annual flow of water of any river in B.C., and the third largest in Canada. The annual average discharge of the Fraser River at Hope is about 2 800 m^3/s, but flows can be as high as 15 000 m^3/s during spring and as low as 400 m^3/s in winter. Its headwaters rise on the western slopes of the Rocky Mountains, near Jasper National Park. During a course of 1 368 km, it drops a distance of 1 109 m to the sea, draining a watershed with a total area of about 228 000 km^2. By the time it reaches the town of Hope, still some 180 km inland from the sea, its surface is only 5 m above sea level.

Topography and climate dominate the hydrological cycle (i.e., the supply and movement of water) in the lower Fraser River basin. Melting snow from the upper slopes of the surrounding mountains feeds the tributary stream and lake systems bordering the basin. In the lowlands, groundwater, slow-moving streams, and seasonal rainfall add to the already considerable flow of the Fraser River.

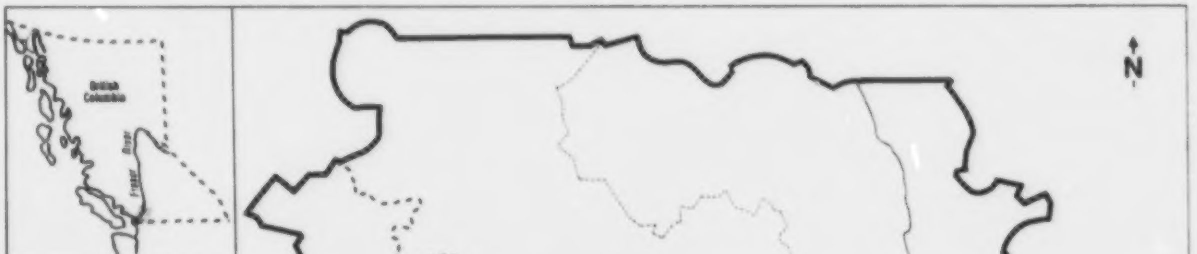
Because the drainage system is largely fed by snowmelt and rainfall, the volume of water it carries fluctuates with the year and the season. For example, in May and June at the peak of the spring freshet, runoff through the Chilliwack and Harrison rivers increases flows in the Fraser by 10–15%. In fall and winter, rainfall can increase flows by up to 45% between Hope and Mission.

At New Westminster, the Fraser splits into the main arm, carrying an estimated 85% of the flow, and the North Arm, carrying the remainder. Tidal influence is felt as far upstream as Chilliwack, and salt water may reach New Westminster under conditions of low seasonal flow and extreme high tides.

The Fraser shapes the topography of its basin by processes of erosion and deposition. Measurements taken at Mission

FIGURE 16.1

Map of the lower Fraser River basin, showing principal political, topographic, and drainage features


British Columbia
Fraser River
N
Coast
Mountains
Fraser River
Greater Vancouver Regional District
Dewdney–Alouette Regional District
Lions Bay
West Vancouver
North Vancouver District
Coquitlam
Vancouver
Burnaby
Pitt Meadows
Maple Ridge
Mission
Richmond
Surrey
Delta
White Rock
Township of Langley
Matsqui
Central Fraser Valley Regional District
Abbotsford
Fraser–Cheam Regional District
Kent
Chilliwack
Hope
Cascade
Mountains
Canada
U.S.A.
U.S.A.
SCALE
0 5 10 15 20
km
Regional District boundary
Municipal boundary

indicate a mean annual sediment load of 17.3 million tonnes, much of which is deposited downstream from New Westminster. In consequence, the Fraser delta is moving into the Strait of Georgia at an average rate of 4.5 m/year, and the mouth of the main channel is advancing by as much as 8.6 m/year (Stewart and Tassone 1989).

The flow regime of the Fraser River is important to the dilution and dispersion of pollutants. Land uses and water withdrawals that alter this regime have a critical impact on water quality. When the river is low, the outgoing tide drastically reduces the diluent capacity of the river, and the incoming tide increases the residence time of contaminants that are discharged into the estuary.

Adjacent to the Fraser drainage system, Burrard Inlet and Indian Arm form a saltwater fjord into which streams flow from the steep coastal watersheds north of Vancouver. Under the influence of tides and currents, the freshwater plume of the Fraser River often extends as far as the mouth of Burrard Inlet.

Land

Repeated crustal uplifting and intrusions of molten material from the Earth's core built the Coast Range mountains. Erosion wore down the mountains and deposited sediments to form the rock that underlies the Fraser lowlands. Glaciation further reduced the mountains, gouged out fjords, and depressed the lowland so that for centuries after the last ice age, postglacial seas flooded the lower reaches of the Fraser basin, laying down fertile marine sediments. Even today, lowland elevations along the Fraser range only from 0 to 150 m above sea level, and few of the surrounding mountains exceed 1 800 m in height.

The soils of the region reflect this geological history. On much of the floodplain of the Fraser, the soils are predominantly of a type known as Humic Gleysols, typified by abundant organic matter, fine texture, and saturation by flooding and groundwater for extended periods of time. On upland sites, the dominant soils are Humo-Ferric Podzols. Formed on coarse-textured, glacial deposits, these soils generally drain so rapidly that nutrients can be leached away in areas of heavy rainfall.

Flora and fauna

Native vegetation developed in response to climate and soils and, of course, the flooding of the river. At lower elevations, in response to relatively warm temperatures, coastal Douglas-fir, western hemlock, and western red cedar predominated. Most of this climax forest has been either harvested or strongly altered by land clearing. In the cooler, moister climate at higher elevations, western hemlock and, eventually, mountain hemlock predominate. On the delta itself, almost all of the native vegetation, mainly shrubs and grasses, has been lost to urban or agricultural use.

The extent, distribution, variety, and quality of habitat are critically important to the well-being of wildlife resources in the lower Fraser River basin. Throughout the region, a remarkable diversity of fresh and salt water and estuarine, intertidal, riparian, and upland settings provides the essential life cycle requirements for richly varied populations of native plants, aquatic invertebrates, insects, fish, birds, and marine and terrestrial mammals.

The lower Fraser River basin supports internationally significant populations of fish and wildlife resources. The lower Fraser River and its tributaries provide critical spawning and rearing habitat for five species of salmon, steelhead and cutthroat trout, and a variety of nonsalmonid species. Of the 73 different species of fish found in the fresh waters of B.C., at least 38 inhabit the lower Fraser River system. Each year, over 50% of the total number of anadromous salmon that are not fished and return to the Fraser River watershed to spawn do so in the lower Fraser River basin. More than 300 species of birds, 45 species of mammals, and 16 species of reptiles and amphibians are found in the lower Fraser Valley and estuary. The Fraser River delta and estuary provide vital habitat for migratory birds of the Pacific Flyway and throughout the winter months support the highest densities of waterfowl, shorebirds, and raptors in Canada.

TRENDS IN ENVIRONMENTAL QUALITY

In broad terms, the natural ecosystems of the lower Fraser River basin have been profoundly influenced by human activities: forestry, fishing, agriculture, and urbanization. In turn, there are two aspects of urbanization, other than the amount of land occupied by buildings, that exert particular pressures on the ecosystem. Combustion of fossil fuels for heating, transportation, and manufacturing diminishes air quality and may contribute to atmospheric changes on a global scale. Excessive waste and improper waste disposal burden land and water with pollutants.

The remainder of this chapter describes the impact of these activities on the environment in the basin of the lower Fraser River and summarizes efforts to correct them.

Factors affecting air quality

The present and future state of the atmospheric environment in the lower Fraser River basin is and will be the result of global trends as well as local influences. Principal issues and concerns include:

- global warming and depletion of the stratospheric ozone layer
- increase in airborne emissions from industry and transport
- problems of high levels of ozone at ground level in localized areas
- vulnerability of lakes and soils to acidic deposition

Climate change

In recent years, the news media have made "greenhouse effect" and "global warming" into household words. Both terms refer to the effect created when carbon dioxide and other gases produced by the burning of fossil fuels absorb infrared radiation emitted by the Earth and reflect it back again, rather than permitting it to be dispersed into space. Although the process has been widely discussed, the potential effects on climate, sea levels, water and soil resources, and biological systems are uncertain.

Several scientific agencies have employed computer models in an attempt to predict the possible effects of global warming.[1] Their projections suggest that a doubling of carbon dioxide concentrations in the atmosphere by the year 2050 could raise year-round average air temperatures in the Fraser Valley by 2.5–5.0°C.

Because warmer air can hold more water vapour, an increase in annual precipitation would be a likely result of warming in the lower Fraser River basin. During the winter months, this would likely occur as rain, rather than snow, even several hundred metres higher in the mountains than is now the case. Higher snow lines and heavier winter rainfall could increase the risk of winter flooding in tributaries of the Fraser that drain low-altitude watersheds, and in urban areas where roofs, roads, and parking lots act as catchment basins. On an annual basis, however, this seasonally increased flow might be offset by a diminished spring freshet, owing to a reduced snowpack in the southern Coast Mountains and the northern Cascades, adjacent to the lower Fraser River basin.

Another prediction is that sea levels will rise by 20–140 cm over the next century as a result of melting of glacial ice and thermal expansion of seawater as the ocean warms. The consequent flooding of coastal wetlands could have a negative impact on substantial populations of waterfowl that breed or winter there, or that use the area as a migratory stopover along the Pacific Flyway.

In addition, warmer water temperatures, higher water levels, and sedimentation due to increased erosion could harm fish that depend on clear, cold water for spawning and the rearing of young.

In view of the scale of events that could be triggered by climatic warming, it may be a wise precaution for authorities in areas such as the lower Fraser River basin to take protective measures. Dikes might need to be constructed or built higher in anticipation of rising sea levels, and reservoirs developed to regulate surface runoff. Additional restrictions might need to be imposed on development and construction on floodplains. Indeed, if warming continues over the long term there will be no choice but to alter current approaches to settlement and land use in the face of major environmental change.

Airborne contaminants

In 1985, human activities were largely responsible for the discharge of 730 000 t of sulphur dioxide, particulates, carbon monoxide, oxides of nitrogen, and volatile organic compounds (VOCs) within the lower Fraser River basin (Greater Vancouver Regional District 1988*a*). More than 70% of this total originated from sources within Greater Vancouver, but air movement patterns carried pollutants as far eastward as the town of Hope.

The burning of fossil fuels (e.g., natural gas, oil, gasoline) is the chief cause of air pollution. Although heating, industry, and open-air burning all contribute their share, mobile sources (e.g., motor vehicles, aircraft, trains) account for the greatest proportion — nearly 85% of total loadings of airborne pollutants in the Greater Vancouver Regional District (1988*a*). Private automobiles are the single largest source of all measured contaminants in the region, with the exception of sulphur dioxide, which comes primarily from industrial sources.

Federal, provincial, and regional authorities have cooperated to establish standards and to monitor levels of air pollution. Canada's three-tiered system of national air quality objectives consists of Level A (desirable: unpolluted); Level B (acceptable: minimal effects on health and environment); Level C (tolerable: abatement required). The Greater Vancouver Regional District (GVRD) air quality index is based upon the national system. Monitoring is conducted at 42 stations (3 of which lie outside the regional district), using 160 samplers (Concord Scientific and Levelton 1989). Figure 16.2 summarizes the 10-year trend: it shows how often levels of six contaminants exceeded certain national air quality objectives. For ozone, the period of record is 1978–88; for the others, 1978–87.

Nitrogen dioxide

Largely a product of internal combustion engines, nitrogen dioxide has shown no discernible trend in the 10-year period. The one-hour Level B objective of 210 ppb was exceeded once, and the 24-hour Level B objective of 110 ppb was exceeded four times. Mean nitrogen dioxide levels were highest in the downtown area, where they approached or exceeded the Level A annual objective of 30 ppb a total of 30 times in the 10-year period (Greater Vancouver Regional District 1988*b*).

Carbon monoxide

Motor vehicle engines produce about 90% of carbon monoxide emissions, which, like those of nitrogen dioxide, showed little trend in the decade. The eight-hour Level A objective of 5 ppm was surpassed on several days in most years at monitoring stations located in areas of high traffic density. These occurrences were most frequent in fall and winter, when air flow patterns do not favour rapid dispersal of pollutants (Greater Vancouver Regional District 1988*b*).

Sulphur dioxide

The combustion of sulphur-bearing fossil fuels, such as oil and coal, produces sulphur dioxide. Relative to other urban areas of comparable size in Canada, emissions of sulphur dioxide are low, because of lower heating requirements and because natural gas

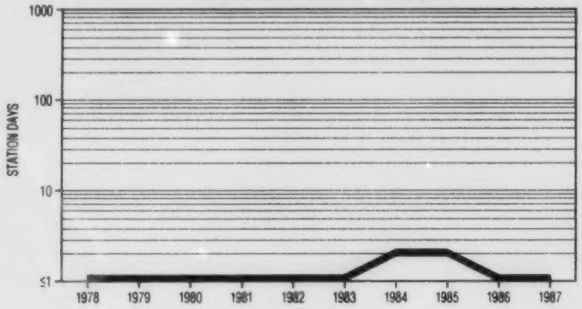
---

[1] Models with particular relevance to the lower Fraser basin have been devised by the Goddard Institute of Space Studies; the Geophysical Fluid Dynamics Laboratory; and Oregon State University.

FIGURE 16.2

Ten-year trends (1978–87) in air quality in the Greater Vancouver Regional District

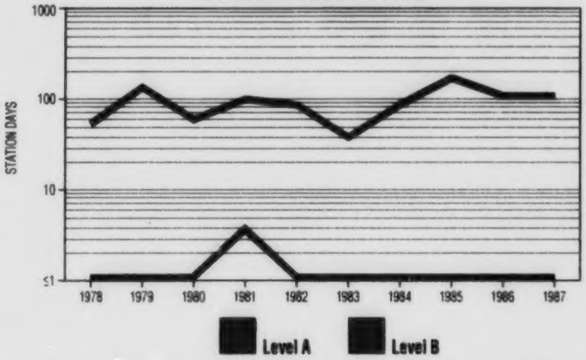
Nitrogen dioxide
Total number of days level B objectives were exceeded at stations T1 through T9



Government of Canada air quality objectives (ppb)

	1-hour	24-hour	1-year
Level A	n.o.	n.o.	30
Level B	210	110	50
Level C	530	160	n.o.

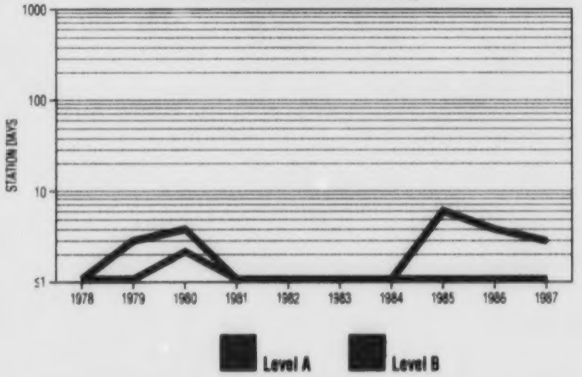
Carbon monoxide
Total number of days objectives were exceeded at stations T1 through T9



Government of Canada air quality objectives (ppm)

	1-hour	8-hour
Level A	13	5
Level B	30	13
Level C	n.o.	18

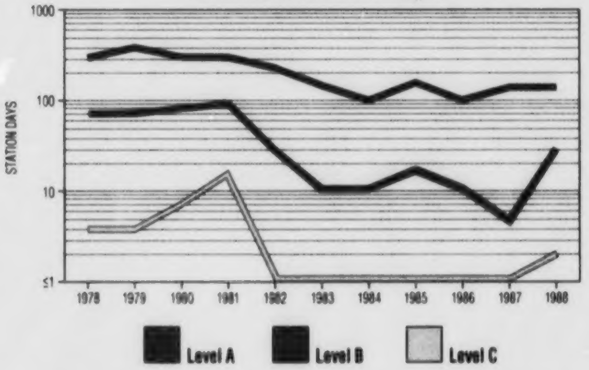
Sulphur dioxide
Total number of days objectives were exceeded at stations T1 through T9



Government of Canada air quality objectives (ppb)

	1-hour	24-hour	1-year
Level A	170	60	10
Level B	340	110	20
Level C	n.o.	310	n.o.

Ozone
Total number of days objectives were exceeded at stations T1 through T9

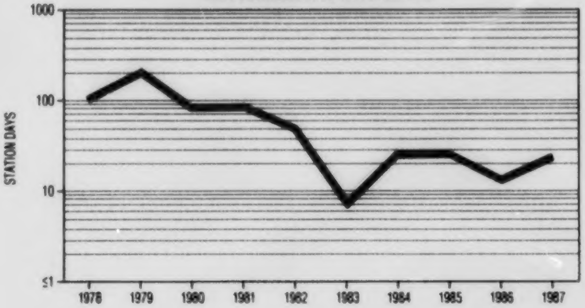


Government of Canada air quality objectives (ppb)

	1-hour	1-year
Level A	51	n.o.
Level B	82	15
Level C	153	n.o.

FIGURE 16.2 (CONT'D)

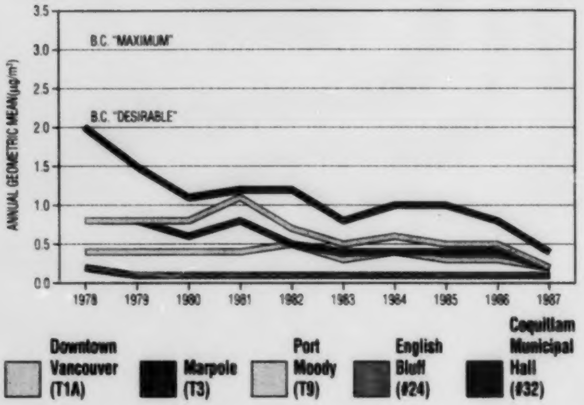
Total suspended particulate
Total number of days the 24-hour level B objectives were exceeded at 32 GVRD stations



Government of Canada air quality objectives (µg/m³)

	24-hour	1-year
Level A	n.o.	60
Level B	120	70
Level C	400	n.o.

Suspended particulate lead



Province of B.C. air quality objectives (µg/m³) (no federal objectives exist for this parameter)

	24-hour	1-year
Desirable	4	2
Maximum	6	3

n.o. means there are no objectives
Source: Greater Vancouver Regional District (1988*b*).

is the predominant heating fuel. The one-hour Level A objective was exceeded on 24 occasions over the decade, usually near major oil refineries (Greater Vancouver Regional District 1988*b*).

Ozone

When sunlight strikes nitrogen oxides and reactive hydrocarbons in the atmosphere, ozone is produced. That is why high ozone levels tend to occur on sunny, summer afternoons in areas of concentrated motor vehicle traffic. Although ozone in the stratosphere performs a protective role by absorbing ultraviolet solar radiation, ozone at ground level is harmful to health and can affect plant growth. It has been estimated that ozone damage to crops in the Fraser Valley totals about $8.8 million annually (City of Vancouver 1990). Between 1978 and 1987, Level A and B ozone objectives were exceeded with declining frequency.

Total suspended particulates

Suspended particulates include smoke, dust, fly ash, and pollen ranging in size from 0.1 to 100 µm. Levels of total suspended particulates declined fairly steadily from 1978 to 1987. Fewer than 3% of particulate measurements taken exceeded the 24-hour Level B objective of 120 µg/m³. Most of these occurrences were associated with wood-processing industries along the Fraser River between Marpole and Coquitlam (Greater Vancouver Regional District 1988*b*).

Suspended lead particulates

The major source of this pollutant was leaded gasoline, and the declining use of this fuel has resulted in a major decline in suspended lead particulate matter. Ambient lead levels in Vancouver have decreased by 75% since 1975 (Environment Canada 1988). Annual concentrations have remained below the "desirable" limit of 2 µg/m³ since 1978, and since 1984 there have been no infringements of the 24-hour limit (4 µg/m³) at any of the 12 monitoring stations (Greater Vancouver Regional District 1988*b*).

Sustaining air quality

Air quality in the lower Fraser River basin is generally good, except during periods of limited air movement, which, as noted above, are often associated with seasonal weather patterns and temperature inversions. Over the past decade, lead levels have dropped dramatically, and the trend for ozone and particulate levels has been generally downward, although recently ozone levels have increased somewhat.

Although sulphur oxides (primarily sulphur dioxide), nitrogen oxides, and suspended particulates are expected to increase by the year 2005, carbon monoxide and hydrocarbons are expected to decrease, owing to planned stringent emission control regulations for automobiles (Table 16.1).

TABLE 16.1

Current and projected air pollutant loadings (in thousands of tonnes per year) in the Greater Vancouver Regional District

Pollutant	Loading 1985	Loading 1995	Loading 2005	% change, 1985–2005
Sulphur oxides	12	16	19	+58
Nitrogen oxides	50	51	55	+10
Suspended particulates	121	136	151	+25
Carbon monoxide	334	236	233	–30
Hydrocarbons	78	66	69	–12
Totals[a]	**595**	**505**	**527**	**–11**

[a] Figures have been rounded off.

Source: Greater Vancouver Regional District (1988*c*).

In the light of growing public awareness of, and concern for, the environment, and as our knowledge of the relationship between air pollutants and human/plant health increases, our concept of acceptable limits may change. Decisions about population growth, distribution, and transportation planning will likely have the greatest influence on air quality in the future. If these relationships are not addressed, levels of carbon monoxide, ozone, and sulphur dioxide will resume an upward trend as traffic volumes and commuting distances increase.

Factors affecting water quality

Water supply and water quality are matters of vital importance within the basin. Water is essential to the native flora and fauna, and human demands for water range from domestic consumption to the needs of industry, agriculture, and recreation. In addition, the river itself performs an important task of diluting and dispersing pollutants.

Some sense of the pressure on water resources can be gained from the knowledge that consumption in the GVRD, as indicated by water billings, increased from 513 L/day per person in 1965 to 751 L/day per person in 1989 (D.A. Maag, Greater Vancouver Water District, personal communication). As the population grows, so does the demand for water. Much of this demand is met from 15 community watersheds in the region, encompassing some 4 200 km^2 (B.C. Ministry of Environment 1980). Additional supplies come from wells. In the eastern Fraser Valley, groundwater use totalled approximately 30 million cubic metres, equivalent to 44% of all water consumed in 1981 (Halstead 1986). In addition to the central issue of water shortages and conflicting demands for use by residential, industrial, agricultural, fisheries, and recreation interests, the following are water-related issues that are of particular concern in the lower Fraser River basin:

- contamination of sediments and biota by organics and metals from industrial and municipal discharges and urban runoff
- nutrient overloading and oxygen depletion in streams and backwaters along the Fraser River and in Boundary Bay owing to wastewater discharges
- seasonally high levels of fecal coliform bacteria from agricultural and urban runoff
- groundwater contamination by leachates from landfill sites
- degradation of shallow aquifers by intensive agriculture

Water management

As the term "floodplain" clearly implies, the lower Fraser River basin is subject to seasonal flooding. A particularly serious flood occurred on the Fraser lowlands in 1894, inundating approximately 708 km^2. Another of similar scale swept the region in 1948, and there is a one-in-three chance that a flood of at least equal severity will occur sometime in the next 60 years (Environment Canada and B.C. Ministry of Environment, no date). This is of particular concern because an estimated 15% of the people in the region live on the floodplain (B.C. Ministry of Environment 1989).

About 574 km of public dikes constitute a major defence against flooding in the lower Fraser River basin. The Fraser River Flood Control Program, launched in 1968, provides funds for improvements to the dike system. From an environmental perspective, of course, diking can have a potentially negative aspect. Dikes can radically alter important intertidal, floodplain, and shoreline habitats.

Between 1979 and 1989, an average of 5.5 million cubic metres of sediment were dredged each year from the lower Fraser to maintain navigation channels (Fraser River Estuary Management Program 1991). Understandably, this dredging disturbs the river-bottom environment, damaging aquatic habitat and, in some cases near industrial areas, stirring up sediments that contain contaminants. For this reason, dredging is restricted during the annual downstream migration of juvenile salmon, and dumping of dredged materials, both on land and at sea, is controlled. River training structures (these direct the flow, prevent meandering) are also used along 20 km of the Fraser River to increase scouring of the river bottom (by rapidly flowing water), thereby reducing the need for dredging.

Water quality trends

On an overall basis, water quality objectives in the main channels of the Fraser are generally being met, and water quality is similar to what it was in 1979 (Fraser River Estuary Management Program 1987*a*). This is due in large measure to the sheer volume of water that flushes contaminants out of the main channels. Nevertheless, in

1983, it was estimated that up to 25% of 148 permitted effluent discharges were causing pollution problems at specific locations (B.C. Ministry of Environment 1985*b*). This is partly because water quality objectives do not apply to the initial dilution zones where, at some discharge locations, toxic conditions persist.

Along the North Arm of the Fraser and in side channels and sloughs, where the flushing effect of the current is poor, water quality is a major concern. Similarly, the water quality in urban streams is generally poor. Both the Brunette and Coquitlam rivers flow through heavily urbanized areas. Local community efforts at rehabilitation have met with considerable success; yet the Brunette remains severely degraded and has experienced many fish kills. The Coquitlam, from whose pristine upper reaches some of Greater Vancouver's drinking water is drawn, suffers chronic siltation problems. In all, of 21 water bodies in the GVRD, water quality is rated poor in 7, fair in 9, and good in only 5 (Greater Vancouver Regional District 1988*d*).

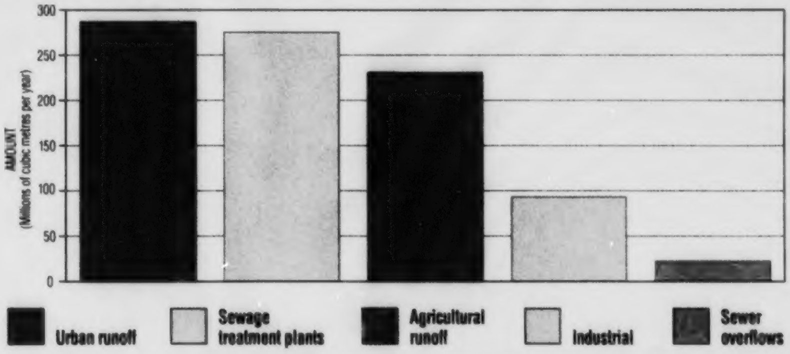
Unless affected by logging operations, mountain streams in the area, such as Kanaka Creek, are relatively pristine. Acid precipitation levels in the basin fall within the range of mild acidity (pH 4.5–5.0), but, due to the high sensitivity of soils and high to moderate sensitivity of lakes, such levels may cause long-term damage (B.C. Ministry of Environment 1985*b*). A lowering of pH levels has been observed, in relation to acid rainfall, in streams that drain areas with little natural buffering capability (Whitfield and Dalley 1987).

In lowland areas, streams that drain agricultural lands or associated urban areas often carry high loadings of nutrients and contaminants, leading to oxygen depletion and frequent fish kills. Several other effects of degraded water are evident as well. Boundary Bay, Sturgeon Bank, and Roberts Bank have been closed to the harvesting of clams and oysters since 1962 because high counts of coliform bacteria make the bivalves unsafe to eat. Opening of a deep-sea outfall from the Iona sewage treatment plant in 1988 resulted in reduced coliform counts at Vancouver area beaches, which had periodically been closed to swimmers. However, on Sturgeon Bank, 25 years of direct discharge from this plant had already severely degraded the estuarine ecosystem.

FIGURE 16.3

Amount (in millions of cubic metres per year) of wastewater that flows into the Fraser River and estuary and into Boundary Bay, by source

The total amount is 908 521 000 m³/year.



Source: Fraser River Estuary Management Program (1990).

Contaminants have been identified in the ecosystem at different locations in the estuary. Metals and organic compounds are of particular concern because they accumulate in the tissues of organisms. Although no definite trends have been observed (Harding *et al.* 1988), analysis over the past 15 years indicates an apparent buildup of contaminants in fish livers (Swain and Walton 1989). Recent concerns have also focused on metals and chlorophenols in the North Arm (Krahn *et al.* 1987), the impact of dioxins and furans on fish and other aquatic life, and the effects of chlorinated organic chemicals on the reproductive success of Great Blue Herons (Elliott *et al.* 1989).

Water pollution

Regulating the use of water for human purposes is perhaps the simplest of the water protection challenges in the lower Fraser River basin. More complex and intractable are the problems posed by the use of the river and estuary as a convenient disposal system in which to dump domestic and industrial wastes.

The main sources of pollution in the lower Fraser are domestic sewage, industrial effluents, and urban and agricultural runoff (Fig. 16.3). Between Hope and Kanaka Creek, point sources alone (i.e., fixed discharge points such as sewage plants and industrial outfalls) contribute 38 million cubic metres of effluent to the Fraser every year (Swain and Holms 1985). Downstream from Kanaka Creek, the annual discharge to the Fraser estuary and Boundary Bay from point and non-point sources combined is estimated to be 865 million cubic metres (Fraser River Estuary Management Program 1990).

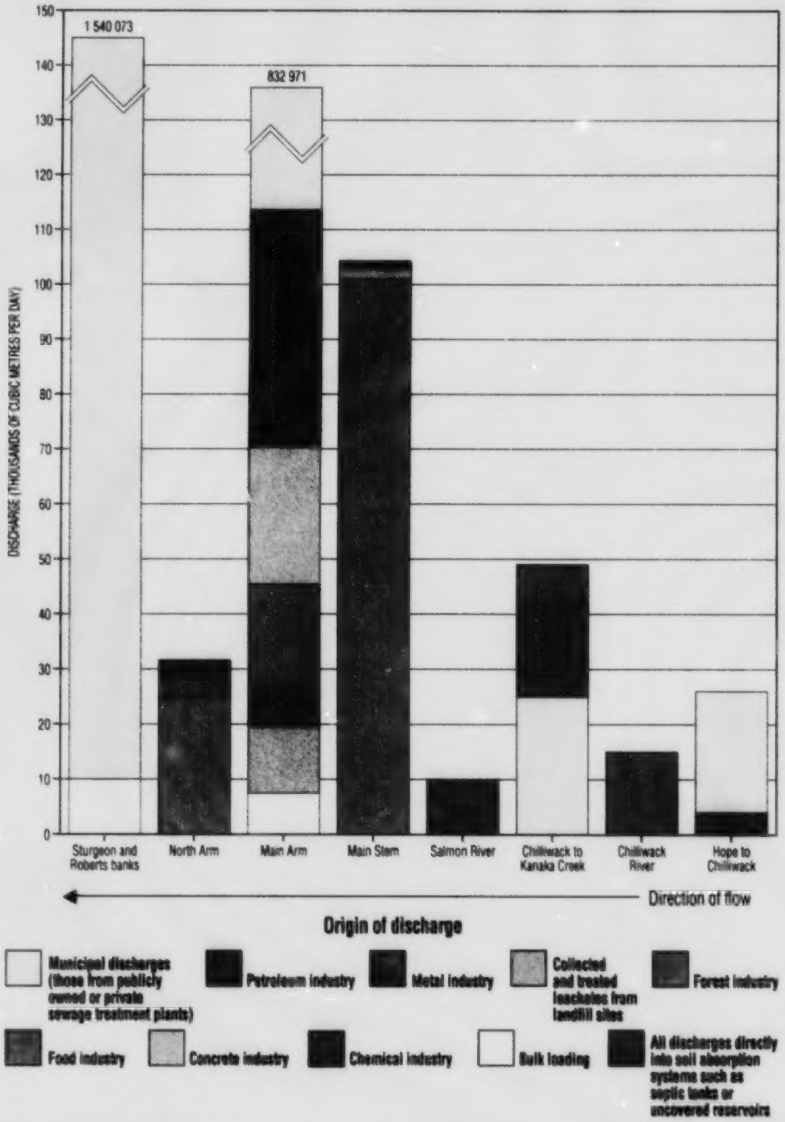
Total quantities of pollutants are hard to gauge, however, especially those from non-point sources. Figure 16.4 shows discharges into the lower Fraser River basin authorized by Ministry of Environment permits, although it should be noted that the actual volume and makeup of flows and the standards of monitoring and reporting by permit holders vary considerably.

Economic growth upstream has also resulted in significantly increased pollution levels. Between 1965 and

FIGURE 16.4

Distribution of discharges in the lower Fraser River basin authorized by B.C. Ministry of Environment permits in 1987

The figure includes the reaches downstream of Hope, through Chilliwack, past the mouth of Kanaka Creek to Sturgeon and Roberts banks. The basins of the Salmon and Chilliwack rivers are tributary basins.



- Origin of discharge refers to the industrial sector originating the discharge.
- Municipal discharges are based on maximum permitted flows, which are much higher than average daily dry weather flows.
- Discharges of less than 1 000 m^3/day are not shown.
- Hope Slough permitted discharges of 1 100 m^3/day, all to soil absorption systems, are included with the Chilliwack to Kanaka Creek discharges.
- Boundary Bay, not shown, had 1987 permitted discharges of 2 795 m^3/day, all but 336 m^3/day to soil absorption systems, and all to its tributaries.
- Sturgeon Bank discharges are dominated by Iona sewage treatment plant effluent, which is discharged to the Strait of Georgia through a deep-sea outfall effective April 1988.

Source: B.C. Ministry of Environment, Waste Management Branch, permit files, 1987; Fraser River Estuary Management Program (1990).

1985, there was a fourfold increase in the quantity of municipal sewage going into the Thompson and upper Fraser rivers, from 32 600 m^3/day to approximately 140 300 m^3/day (Servizi 1989). During the same period, daily industrial discharges from upstream sources (notably six new pulp and paper mills) rose dramatically from 1 400 m^3 to 643 900 m^3.

Sewage

Human settlements produce human wastes. When overall quantities were small, sewage disposal was not seen as a problem within the region. As the population has grown and the quantity of sewage has increased in proportion, treatment and disposal have become a major concern in the GVRD.

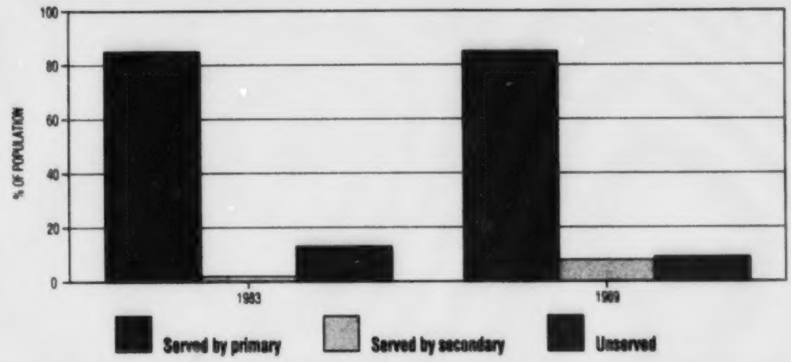
Over 90% of the domestic effluent produced in the lower Fraser River basin flows through three primary sewage treatment plants located in the Fraser estuary, at Iona Island, Lulu Island, and Annacis Island. Collectively, and depending on weather conditions, they handle from 750 000 m^3 to more than 2 million cubic metres of effluent per day (Greater Vancouver Regional District 1988*d*): that is to say, enough sewage to fill B.C. Place Stadium 160 times a year.

Between Kanaka Creek and Hope, secondary treatment plants in six municipalities discharge about 35 000 m^3 per day into the lower Fraser (B.C. Ministry of Environment, Waste Management Branch, file data). However, this amount is dwarfed by discharge from the rapidly growing Lower Mainland communities of Surrey, Maple Ridge, Langley, and Coquitlam. Together, these municipalities account for 60% of the increase in sewage flow since 1976, all directed to the Annacis Island plant. Furthermore, the volume of flow from this plant is expected to double in the next 45 years.

The level of sewage treatment in the region is being improved. Figure 16.5 indicates the 1983–89 changes in percentage of population served by different levels of sewage treatment.

FIGURE 16.6

Percentage of the population served by sewage treatment in Vancouver, Matsqui, and Chilliwack Census Metropolitan Areas, 1983–89



1983 population served: 1 409 402
1989 population served: 1 637 595
Source: Environment Canada, Inland Waters Directorate, Municipal Water Use Data.

A major river system can absorb and disperse certain amounts of waste without showing immediate ill effects. However, when effluents are discharged into a tidal stream such as the lower Fraser River, the flow of the tide does not always favour rapid dispersal. At slack tide, for example, effluent from the Annacis Island plant can pool and spread across the breadth of the river in as little as two hours. During certain times of the year, millions of juvenile salmon and eulachon larvae must traverse this noxious band of polluted water (Birtwell *et al.* 1988). If the river flow happens to be low, effluent concentrations may linger in the river for up to two days. The lethal and sublethal effects of contaminants on fish have been identified. There are, however, no techniques currently in place to link these effects to overall impacts on fish populations (Birtwell *et al.* 1988).

A further cause for concern is the addition of toxic heavy metal and organic contaminants to the domestic sewage flow, via industrial connections to municipal sewer systems. These substances are not generally removed by primary treatment and may cause lethal or sublethal effects on aquatic organisms as a result of accumulation in body tissues.

Industrial effluents

The thriving economy of the lower Fraser River basin includes chemical, construction, food, forest products, metalworking, petroleum, and shipping industries, all of which generate wastes. Many companies have been granted permission to discharge contaminants directly into the river. Authorized direct discharges currently amount to about 300 000 m^3 every day (B.C. Ministry of Environment, Waste Management Branch, file data). This total is down from the 1973 level of 351 571 m^3/day (Hoos and Packman 1974), largely because of the diversion of industrial wastes to the Annacis Island sewage treatment plant, which was completed in 1975. The true figure may be much higher, however, given that some permit holders exceed their allowable limits, and others may be discharging wastes without authorization (Fraser River Estuary Management Program 1990).

Industrial contaminants include oil, grease, suspended solids, metals such as lead, copper, cadmium, chromium, manganese, nickel, and zinc, as well as dozens of organic compounds. Many of these substances are toxic to living organisms, some alter pH levels (acidity), and others deplete dissolved oxygen in the water through the biological and/or chemical processes of decomposition.

In addition to authorized industrial discharges, recent attention has focused on operations using chlorophenols as wood preservatives and other antisapstain products (see Chapter 10). Average chlorophenol loadings for the Fraser River below Kanaka Creek have been estimated at 490 kg/year from 25 operations (Krahn *et al.* 1987). In 1989, the B.C. Ministry of Environment introduced controls under the *Waste Management Act*, which establishes maximum discharge levels for these chemicals both to storm sewers and to runoff from areas where treated lumber is stored. Chlorophenol use is declining as forest companies change to other preservatives.

Urban runoff

Prior to extensive urban settlement in the lower Fraser River basin, the impact of rainfall on the watershed was buffered by forests and absorbent soils. The replacement of natural cover by paved roads and parking lots, rooftops, and other nonabsorbent structures has created an enormous catchment area from which rainfall is channelled to the river, the estuary, and adjacent coastal waters.

Storm sewers and ditches discharge urban runoff at numerous points in the basin. Annual urban runoff through storm sewers and ditches contributes about 165 million cubic metres of water to the Fraser estuary, and another 122 million cubic metres per year flows into Boundary Bay (Greater Vancouver Regional District 1988*e*). Samples of runoff water indicate that it contains higher concentrations of nutrients and metals than the river (Swain 1983; Lawson *et al.* 1985). In some areas, combined storm and domestic sewer systems pass stormwater through sewage treatment plants, resulting in capacity overflows of urban runoff and raw sewage during storms. There are 22 combined sewer overflow points on the main stem and North Arm of the river, with annual flows of 22 million cubic metres (Greater Vancouver Regional District 1988*e*).

Agricultural discharges

The intensification of agricultural practices on both the lower Fraser floodplain and the adjacent upland has diminished the absorptive properties of the land area. As a result, applications of manure, chemical fertilizers, and pesticides have contributed to the contamination of ditches and adjacent waterways. Furthermore, nutrients, bacteria, and metals in agricultural runoff increased substantially between 1979 and 1987. Nutrients create high biochemical oxygen demand (BOD) in bodies of water by stimulating growth of algae. When the algal population crashes, the processes of decay use up oxygen. The combination of oxygen depletion and dissolved toxic substances has caused fish kills in a number of the smaller tributaries flowing into the Fraser. Although it is difficult to establish precise figures over a large area, it is estimated that the total runoff from farmland into the estuary below Kanaka Creek could average 632 000 m^3/day (Greater Vancouver Regional District 1988*f*). This issue is the focus of a current federal–provincial soil conservation agreement.

Miscellaneous sources

Apart from the major contaminant sources cited above, pollutants may enter the river through seepage from landfills or underground storage tanks, accidental or deliberate discharges from houseboats or ships, and construction operations or bridge sandblasting. During 1984–86, there were 61 reported spills of chemicals or oil in the Fraser estuary (Fraser River Estuary Management Program 1987*b*); there is no way of knowing the numbers, kinds, and volumes of other spills that may have gone unreported. Airborne contaminants also contribute to water pollution, as do dissolved chemicals from preservative-treated wharf timbers, anti-fouling paint on boat hulls, and leachates from wood wastes used as landfill (Greater Vancouver Regional District 1988*f*).

Sustaining water resources

Does water quality in the lower Fraser River basin provide for a healthy environment to meet the needs of humans, fish, and wildlife? Too little information exists to answer this basic question. Available data suggest that, outside the initial dilution zones, water quality in the main channels of the Fraser has not deteriorated substantially over the last 10 years. However, as noted above, there are serious trouble spots, especially in urban streams and wherever natural flushing is inadequate to disperse pollution. There are also uncertainties about the bioaccumulation of contaminants in fish and wildlife.

The setting of provisional water quality objectives by the British Columbia Ministry of Environment and the inclusion of these in a water quality plan by the Fraser River Estuary Management Program mark an important step towards establishing baseline conditions. Much more remains to be done. Extensive monitoring will be necessary, especially of chlorophenols, heavy metals, and organic contaminants in surface waters, sediments, and biota, and of nitrates and organic contaminants in groundwater. Bioassays and monitoring of contaminants in sediments and organisms are also required. There is also a need for consistent monitoring procedures at sites where municipal and industrial effluents are discharged. The current lack of ambient monitoring in the initial dilution zones means that concentrated pesticide runoffs, contaminant plumes, and toxic or anoxic (oxygen-depleted) conditions near outfalls may go undetected.

Factors affecting flora and fauna

Human activity in the lower Fraser River basin during the past two centuries has had a profound impact on species that were native to the area long before the arrival of humans. However, more than 300 species of birds, 46 species of mammals, and 16 species of reptiles and amphibians are still found in the lower Fraser Valley and estuary (Butler and Campbell 1987). A few additional species occur in the adjacent mountains, and at least 87 species of fish, as well as hundreds of plants and thousands of invertebrates, are native to the region.

Habitats and populations

Several trends can be expected to influence the sustainability of fish and wildlife populations and habitat:

- loss of wetlands to urban growth, flood control measures, and drainage schemes
- depletion of stocks of salmon and freshwater fish, due to overfishing and habitat loss
- degradation of stream and estuary habitat, resulting from inappropriate land use
- elimination or alteration of forest and other upland habitat, due to urban growth and timber harvesting

In addition, populations and habitats may be affected by toxic effects of agricultural pesticides and fertilizers, and cropping practices can alter the distribution of wildlife species.

Aquatic habitats

The waters of the lower Fraser River basin are naturally productive aquatic habitats that support at least 87 resident and migratory species of saltwater, freshwater, and anadromous (migratory) fish at various stages of their life cycle. The entire chum salmon stock of the Fraser system, as well as three-quarters of the pink and coho salmon, one-third of the chinook, and one-eighth of the sockeye, spawn in the lower Fraser River basin (Farwell *et al.* 1987). In an average year, more than 800 million juvenile salmon migrate through the lower Fraser River to the sea (Department of Fisheries and Oceans 1988). In contrast to the abundance of the salmon, the endangered Salish sucker, one of the rarest fish in Canada, inhabits the upper reaches of a few cool, slow-moving streams southeast of Vancouver (Burnett *et al.* 1989).

Seaward, beyond the Fraser estuary, lies the Strait of Georgia, inhabited by numerous species of fish and invertebrates. Sea mammals such as killer whale, harbour seal, and sea lion, frequent these waters, as do many seabirds (Butler and Campbell 1987).

Wetland habitats

The delta wetlands provide vitally important habitat for migratory birds of the Pacific Flyway. Intertidal flats and marshes support an average of half a million waterfowl, gulls, and shorebirds, and up to 1.4 million birds have been recorded in some years during peak migration periods (Butler and Campbell 1987).

From October to April, snow geese feed on the foreshore marshes and adjacent fields by the tens of thousands. Throughout the winter months, no other location in Canada supports such high densities of waterfowl, shorebirds, and raptors as the Fraser River delta (Butler and Campbell 1987; Campbell *et al.* 1990).

Upland habitats

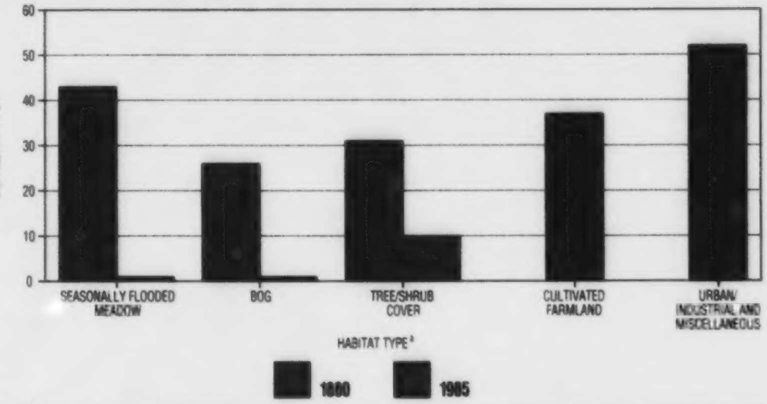
The higher ground of the region consists of three natural habitat zones. Listed in order of increasing altitude the zones are Coastal Western Hemlock, Mountain Hemlock, and Alpine Tundra (B.C. Ministry of Forests 1988). Although logging, agriculture, and urban growth are progressively altering or eliminating the natural forest vegetation over large areas, significant wildlife populations continue to survive. Big game species such as the black-tailed deer, black bear, and mountain goat still occur in appropriate locations. Fifteen species of furbearing mammals, including squirrels, muskrat, weasel, and raccoon, inhabit the region, as do a wide variety of songbirds, upland game birds, and raptors. Some seasonal concentrations are noteworthy. The Harrison River area, for example, supports a large population of Bald Eagles during autumn and early winter.

Habitat alterations

Human activity in the lower Fraser River basin has imposed major changes on ecosystems and wildlife populations throughout the region. Although the loss of physical habitat may be responsible for declining fish production, there is also concern over the deteriorating quality of the habitat in terms of water quality and low flows in some smaller streams. As noted previously, agricultural runoff, municipal sewage, and industrial effluents all contribute to toxic and anoxic conditions in streams and channels where pollutants are not readily flushed out.

FIGURE 16.6

Approximate percentage of lands in the Fraser River delta occupied by various habitat types[a] in 1880 and 1985



[a] Includes only lands above mean high tide.

Source: Butler and Campbell (1987).

Alterations of habitat have been dramatic in the wetlands of the delta and estuary. For example, wetlands in a portion of the southwestern Fraser lowlands declined by 27% between 1967 and 1982 (Pilon and Kerr 1984). Inventories in the foreshore of the Fraser River estuary indicate 3 274 ha of intertidal marsh habitat and 193 km of riparian habitat remain (Williams 1986; Kistritz 1989). Figure 16.6 indicates the change in habitat composition of lands in the Fraser River delta over the past century.

Upstream from the Fraser River delta, other wetlands have been lost to diking and drainage projects. At the former Sumas Lake (near Abbotsford), 11 700 ha were drained in the 1920s, and significant wetland areas have also been lost at Pitt Polder (a diked area on the eastern bank of the Pitt River) and Cheam Lake (near Chilliwack), and along major reaches of the Fraser River.

The impact of habitat loss on wildlife has been significant. Bird species that once nested in the basin but no longer do so include the Yellow-billed Cuckoo, Purple Martin, Western Bluebird, Horned Lark, and Burrowing Owl. Still others, like the Barn Owl, Sandhill Crane, and Yellow-headed Blackbird, nest in very small numbers in the delta area and are declining due to habitat loss (Butler and Campbell 1987). Waterfowl species that historically migrated through the delta in large numbers — e.g., Greater White-fronted Goose, Brant, and some races of the Canada Goose — now occur in much smaller numbers (Leach 1982). Even in the remotest uplands, forest management practices involving short rotations threaten species, like the Spotted Owl, which require old-growth trees for nesting.

Mammals in the basin have also been affected by human settlement and land use. Roosevelt elk were extirpated from the region by early settlers. Large carnivores like the wolf, cougar, and black bear are now restricted primarily to remote forest habitats. Several kinds of small mammals characteristic of the Puget lowlands of Washington occur in Canada only in the Fraser Valley, where they are now restricted to small remnants of their former habitat.

TABLE 16.2

Average numbers (in thousands) of five species of salmon caught by the commercial, recreational, and native fisheries and escapements (numbers that survive all fisheries and return to spawning grounds), 1981–86

	Chinook	Coho	Sockeye	Pink[a]	Chum	Total
Commercial						
Canada	163.2	338.1	5 766.8	5 538.5	241.9	12 048.5
United States	0	0	1 989.8	1 578.8	45.0	3 613.6
Subtotal	163.2	338.1	7 756.6	7 117.3	286.9	15 662.1
Recreational	115.9	97.8	0	0	0	213.7
Native	19.4	29.8	434.0	81.3	14.5	579.0
Total catch	**298.5**	**465.7**	**8 190.6**	**7 198.6**	**301.4**	**16 454.8**
Escapements[b]	106.4	58.2	1 902.6	5 139.5	511.0	7 717.7
Total return (catch plus escapements)	**404.9**	**523.9**	**10 093.2**	**12 338.1**	**812.4**	**24 172.5**

[a] Pink returns based on odd-year returns.

[b] Escapements averaged over 1981–85.

Source: Farwell *et al.* (1987); B. Masse, Department of Fisheries and Oceans, personal communication.

Other more opportunistic species that thrive in farmland or urban settings have prospered with the expansion of human settlement. Obvious examples include imports such as the European Starling, House Sparrow, and Ring-necked Pheasant, as well as the native Red-winged Blackbird, American Robin, and Brown-headed Cowbird. The last of these, true to its name, is attracted to cattle and has become common in the floodplain and delta since the establishment of an extensive dairy-farming industry.

Nonconsumptive uses of wildlife

Nature-related tourism and recreation are fast-growing, potentially nonconsumptive uses of the environment. Recent surveys indicate important growth potential for wildlife-related tourism in British Columbia. A total of 51 choice wildlife viewing sites have been identified, 5 in the lower Fraser River basin (Ethos Consulting *et al.* 1988). In the Fraser delta, 70 000 – 100 000 visits are made annually to the George C. Reifel Migratory Bird Sanctuary, primarily to see large flocks of snow geese. Boat tours provide many visitors with opportunities for close observation of sea lions that haul out at the river mouth during the annual eulachon runs. Wildlife viewing experiences like these offer considerable potential for nonconsumptive use.

Fisheries

Apart from the nonconsumptive opportunities, many consumptive uses of fish and wildlife resources can be sustainable if they are managed with a heightened sense of stewardship. Sustaining the fisheries of the lower Fraser River basin is a formidable challenge. Salmon, trout, and at least six commercially important nonsalmonid finfish and five shellfish species inhabit the basin. They form the foundation of three economically significant fisheries: commercial, recreational, and native. Salmonid fishes dominate all three.

Between 1981 and 1986, the average annual commercial catch of Fraser River salmon was 15.6 million fish (Table 16.2). Average annual catches have generally increased, because of larger catches of pink and sockeye salmon. The commercial catch of coho, chum, and chinook salmon has declined. In 1987, the total wholesale value of the commercial fishery from the Fraser River was more than $270 million, of which about one-third came from stocks within the lower Fraser River basin (Department of Fisheries and Oceans 1989). The recreational fishery consumes far fewer fish than the commercial fishery. In 1981–86, the average number of salmon taken by anglers each year was 213 700, less than 2% of the commercial catch (Table 16.2).

About 85% of angler effort takes place in freshwater locations, where the presumed maximum allowable catch is much lower than at sea (Table 16.3). In 1984, the B.C. Ministry of Environment's Lower Mainland Region Fisheries Management Plan forecast a doubling of angler effort in freshwater lakes, rivers, and streams between 1980 and 1990. Such an increase, if realized, was expected to result in a catch that would exceed the maximum allowable harvest of salmonid species in freshwater habitats.[2]

Native peoples have been harvesting salmon, steelhead trout, eulachon, and sturgeon from the lower Fraser River for thousands of years. The fishery plays an essential role in their culture and economy. Since 1888, they have been specifically authorized to take quantities of salmon for food and ceremonial purposes. In recent years, this

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[2] Projected future fish catch is based on Ministry of Environment criteria for acceptable angler success rates; these minimum criteria vary according to species and habitat type, but are generally 0.2 fish per angler-day for rivers and streams, and 1.0 fish per angler-day for lakes.

TABLE 16.3

Recreational freshwater fishing: catch, effort, production estimates, and projections for the lower Fraser River basin[a]

Habitat type	Quantity	Estimated production (1980)	Catch (1980)	Angler-days 1980	Maximum harvest[b]	Projected[c] catch, 1990	Projected[c] angler-days, 1990
Large lakes	11	122 500	22 000	31 000	44 000	36 150–99 200	50 000
Small lakes							
– low elevation	185	606 800	249 000	259 000	300 000	393 800–841 050	422 000
– high elevation	667	93 700	18 000	18 000	29 000	28 650–57 300	28 000
River and streams	847 km	250 300	34 000	241 200	91 000[d]	43 545–61 700	440 000
Total		**1 073 300**	**323 000**	**549 200**	**464 000**	**502 145–1 059 250**	**940 000**

[a] Data pertain to the Fraser-Delta, Pitt, Lillooet, and Skagit planning units and include some areas beyond the basin boundaries.

[b] Maximum harvest refers to the number of fish that may be continuously harvested under existing conditions to maintain the same level of production into the future.

[c] Projected catch and projected angler-days refer to 1984 projections for 1990.

[d] Nonsalmonid freshwater fish constitute 72 000 (80%) of the estimated maximum harvest in river and stream habitat.

Source: B.C. Ministry of Environment (1985*a*).

catch has increased significantly. During the 1950s, the average annual catch was 116 737 fish, but between 1981 and 1986 the average rose to 579 000.

The traditional importance of the salmon to native people, combined with increasing pressure on the stocks, puts the question of fisheries allocation at the centre of aboriginal land and sea claims. Successfully balancing the demands of all three fisheries with the imperative to conserve viable salmon populations will be a crucial test of sustainability for this resource.

Sustaining fish and wildlife habitat

Excluding parks and recreation areas, 15 994 ha of land in the lower Fraser River basin, mostly in lowland locations, receive some degree of protection in wildlife conservation areas (Table 16.4). Considering the pressures placed on land and water resources by forestry, agriculture, and urbanization, the fact that less than 1% of the region is specifically reserved and protected for the use of wildlife and the preservation of ecosystems raises serious questions about long-term sustainability.

This is of particular concern in the Fraser Valley lowlands, where the most distinctive and productive habitats occur, but where most land is in private tenure, and settlement and agricultural uses are rapidly consuming the remaining wildland. Of nine ecological reserves in the basin, only three encompass lowland habitats in the Fraser Valley (B.C. Ministry of Parks 1990), and these are small and easily disrupted by surrounding land uses. Although the basin has a sizable area of land in park and recreation status, and this also supports wildlife, there is virtually none of it in the lowlands.

Many fish stocks have declined, and many bird populations have fallen far below historical levels. At least six vertebrate species have been extirpated, and the Committee on the Status of Endangered Wildlife in Canada has listed two others as endangered.

It has been stated that "the greatest threat to birds in the Fraser delta is loss of a place to live" (Butler and Campbell 1987). In the lowland and delta areas, pressures of urban and agricultural development are steadily diminishing the remnants of riparian, meadow, and wetland habitat. In the uplands, many stands of older trees that provide winter range for ungulates and essential habitat for cavity-nesting birds are scheduled to be logged.

Although physical loss of habitat is a major problem, it is not necessarily any more serious than degradation of habitat quality. Many species of birds that occupy niches at or near the top of the food chain are sensitive indicators of ecosystem health. Within the lower Fraser River basin, the Great Blue Heron is one of a number of species that are monitored regularly to assess the level of several toxic substances in the environment. Analyses of Great Blue Heron eggs from a colony in the University of British Columbia's Endowment Lands indicated that from 1983 to 1989 there was a steady increase in levels of 2,3,7,8-TCDD, a highly toxic form of dioxin. Studies at the same colony for the period 1977–87 revealed a steady decline in levels of PCBs and of DDE, which may be produced when the insecticide DDT begins to break

TABLE 16.4

Wildlife conservation areas in the lower Fraser River basin

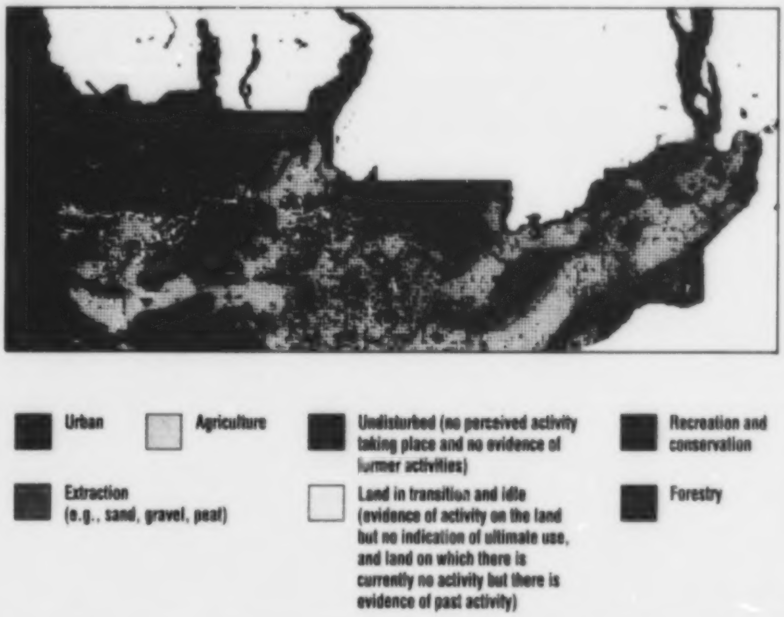
Type	Area (ha)
Federal migratory bird sanctuaries and wildlife areas	737
Provincial ecological reserves	616
Wildlife management areas	3 833
Crown "map reserves" and "notations of interest"[a]	10 808
Total	**15 994**

[a] Map reserves and notations of interest are administrative designations that, in this case, either reserve provincial Crown land for wildlife or indicate lands where the provincial Wildlife Branch has expressed an interest. That interest is taken into account when applications for other uses of the land are considered.

Sources: D. Trethewey, Environment Canada, personal communication; Nature Trust of British Columbia (1988); L. Foubister, B.C. Ministry of Environment, personal communication; B.C. Ministry of Parks (1990).

FIGURE 16.7

General patterns of land use in the lower Fraser Valley, 1986–87


Urban
Agriculture
Undisturbed (no perceived activity taking place and no evidence of former activities)
Recreation and conservation
Extraction (e.g., sand, gravel, peat)
Land in transition and idle (evidence of activity on the land but no indication of ultimate use, and land on which there is currently no activity but there is evidence of past activity)
Forestry

Source: Moore (1990).

down (Whitehead 1989; Whitehead *et al.* 1989). Elsewhere in the region, at least eight bird kills in recent years have been traceable to the application of agricultural pesticides (Butler and Campbell 1987). (Chapter 21 discusses these and other toxic chemicals.)

In the aquatic environment, fish stocks face the combined pressure of habitat degradation and declining water quality on one hand, and increased harvesting on the other. Anadromous trout populations, especially steelhead, have increased due to restrictive harvest regulations and hatchery enhancement programs. However, trout that rely on small stream habitat (i.e., cutthroat trout) are expected to decrease due to habitat loss and pollution. Dolly Varden and sturgeon are also considered at risk from overharvest and habitat loss; hatchery and other enhancement techniques are not expected to add significantly to their numbers in the future.

Added to the conflicting demands of commercial, recreational, and native fisheries within the region is the pressure of offshore driftnet fishing in international waters. External problems such as global warming, acid rain, and reduced or irregular water flows may also be expected to add to the stress on fish populations.

Efforts to increase fish populations (e.g., the Salmonid Enhancement Program) and to protect habitat through implementation of a "no net loss" policy are ongoing. Still, increasing demands and pressures on the resource base are cause for serious concern about the sustainability of the fisheries.

Factors affecting land use

The diversity of natural characteristics, coupled with a rapidly expanding and urbanizing population, has given rise to a wide range and complex pattern of land uses (Fig. 16.7). Not surprisingly, several pressing issues have emerged in relation to land and land use in the lower Fraser River basin, including:

- preservation of "urban edge" natural areas for recreation
- conflicts between single and multiple values of forests
- environmental impacts of forest industry practices
- encroachment of urban growth on agricultural land
- impact of agricultural practices on soil quality
- problems related to disposal of solid waste
- inadequate disposal facilities for hazardous wastes

Parks and recreation

The natural ecosystems of the lower Fraser River basin offer opportunities for hiking, wildlife viewing, boating, hunting, fishing, and many other active and passive outdoor pursuits. As more people migrate to the area, however, they place increasing demands on recreational and leisure resources. One indication of this growing demand is the fact that from 1976 to 1988 the GVRD increased the area allocated for parkland by 88% (Watmough 1987).

At present, park and recreation areas (excluding nature conservation reserves) occupy a total of 131 351 ha, or 7.7% of the basin. These major parks and recreation areas recorded 8.7 million visitor-days in 1988 (Table 16.5). Some sense of the growing demand for parks can be gained from visitor statistics for Deas Island and Derby Reach parks, where annual attendance increased nearly fivefold, from 80 000 in 1984 to 352 000 in 1987 (Kennett and McPhee 1988).

In addition to parks, many undesignated areas are also used for recreation. Dikes and causeways provide access to the Fraser River for anglers, bird watchers, and many other outdoor enthusiasts. The City of Richmond is seeking to establish a dike perimeter trail around Lulu and Sea islands to provide more waterfront access to the public (Kennett and McPhee 1988).

Wildlife viewing, especially bird watching, is a rapidly growing recreational activity for both residents and tourists. The Boundary Bay ecosystem, in particular, is an internationally significant wintering ground and migration rest stop along the Pacific Flyway, affording opportunities to view over 200 bird species on a regular basis, and 90 more that appear as occasional visitors. Sport fishing is another popular leisure pastime. Freshwater lakes, rivers, and streams of the lower Fraser River basin supported some 550 000 angler-days in 1980 (B.C. Ministry of Environment 1985*a*). For both these recreational activities, protection of water quality and fish and wildlife habitat is closely tied to continued enjoyment.

Forestry

Excluding parks, half the lower Fraser River basin is designated as public forest land, and forestry has played a long and important economic role in the history of the area. Critical factors affecting the sustainability of forest resources include the supply and capability of land for timber production, the rate of harvest, losses from natural causes, and the level of management activity, including the degree to which managers consider the whole forest ecosystem.

The lower Fraser River basin includes not only 11 680 km^2 of forest lying within the Fraser Timber Supply Area (TSA), but also the GVRD (580 km^2), the District of Mission Tree Farm Licence (89 km^2), the University of British Columbia Research Forest (51 km^2), and the Scott Paper Tree Farm Licence (36 km^2). Of 5 193 km^2 of productive forest within the Crown Forest Land (TSA) portion of the basin, 2.3% (120 km^2) is classed as being on good growing sites, 38.7% (2 011 km^2) is on medium growing sites, and 59% (3 062 km^2) is poor or very poor forest land (B.C. Ministry of Forests 1985).

TABLE 16.5

Types and numbers of parks and other recreation areas in the lower Fraser River basin and number of visits (calculated as visitor-days), in 1988

Type	No.	Area (ha)	No. of visits
Federal park	1	8	83 758
Provincial parks	16	114 364	5 433 995
Forest recreation areas	3	2 712	nd
Forest recreation sites	50	n/a	38 000[a]
Regional parks	20	9 137	2 813 791
B.C. Hydro recreation areas	4	420	397 369
Major municipal parks	nd	4 710[b]	nd
Total		**131 351**	**8 766 913**

nd means no data; n/a means not available

[a] Refers to "satisfactory user day opportunities."

[b] Includes only major municipal parks; does not include data for the Regional District of Fraser-Cheam

Source: Dewdney-Alouette Regional District (1983); B.C. Ministry of Forests (1985); Greater Vancouver Regional District (1988*f*); B.C. Ministry of Parks (1988).

The timber harvest is set in accordance with the estimated maximum sustained yield of the forest. The annual allowable cut of 1.9 million cubic metres applies to all public forest land and is valued at $260 million, $230 million of which is derived from the Fraser TSA. In the case of Crown TSA lands, the annual allowable cut represents 1.7 million cubic metres (Jacques 1988).

On the basis of existing timber volume and age, projections have been made for a 200-year harvest cycle. Theoretically, this indicates a constant yield of 1.7 million cubic metres for the next 40 years. Thereafter, the annual harvest would need to be reduced by about 18% between the 50th and the 80th years, when it could then return to the present level for the remainder of the cycle (B.C. Ministry of Forests 1985).

Even on a theoretical basis, notwithstanding current shifts in public perception of timber production versus other forest values, this projection, of course, assumes that several key variables (e.g., the available land base; the level of productivity; the demand for product) will remain constant over a period of two centuries — a highly unlikely scenario. In recent years, the annual harvest has regularly exceeded the allowable cut. However, averaged over five-year management periods, the excess has been within 10% of the annual allowable cut, as required by legislation.

Apart from logging, timber resources are consumed by fire, pests, and disease. In 1986–88 (with unusually severe fire conditions in 1986), more than 60 000 m^3 of timber went up in smoke — far more than the forecast annual fire loss of 5 000 m^3. Losses to insects and diseases amount to 100 000 m^3 annually.

Central to the goal of sustainability in timber supply is the renewal of forests through silviculture — i.e., the planting and management of trees to replace those that are cut and to increase the production of wood from a given area of forest. In 1986–88, crop renewal planting took place on 6 837 ha and crop enhancement planting on a further 1 217 ha of land in the Fraser TSA (Table 16.6).

There are other values in forest land besides the economic yield of timber harvesting, however, and there is increasing demand that these other values should also be sustained. Tourism and recreation, conservation of fish and wildlife habitat, old-growth preservation, and protection of water supplies are all activities that must be

TABLE 16.6

Silvicultural activities in the Fraser Timber Supply Area, 1986–88

Activity	Target (ha)	Achieved (ha)
Crop renewal:		
Planting	5 912	6 837
Site preparation	1 131	302
Brushing and weeding	2 176	1 812
Surveys	10 977	15 546
Subtotal	20 196	24 497
Crop enhancement:		
Planting	1 420	1 217
Conversion[a]	589	406
Fertilization	4 650	2 199
Juvenile spacing	4 018	1 648
Subtotal	10 677	5 470
Total	**30 873**	**29 967**

[a] Converting to commercially usable species from noncommercial brush species.

Source: B.C. Ministry of Forests (1989).

accommodated. In many instances, these activities are inconsistent with the conventional forest industry objective of maximizing timber yield. These competing priorities will have to be weighed against harvest projections to achieve true sustainability of forest resources.

Agriculture

Favourable climate and fertile soils make the lower Fraser River basin one of the most agriculturally productive areas in Canada. The average quality of agricultural land is much higher than for British Columbia as a whole. High capability lands (Canada Land Inventory classes 1–3) compose 40.5% of the Agricultural Land Reserve (ALR) in the lower Fraser River basin, compared to only 22.7% of the entire ALR of the province (B.C. Ministry of Agriculture and Fisheries 1988). At present, some 5 600 farms, occupying about 890 km^2 of land, produce 50% of the gross farm income in the province (Statistics Canada 1987). The annual value of this agricultural production is about $588 million, not counting the spin-off effects of processing and marketing. This amounts to an average return of $6 600 per hectare, which is more than 14 times the national average.

At the same time, rapid urban growth has placed severe pressure on this valuable agricultural land. The rate at which farmland was being converted to nonagricultural uses was slowed in 1973 by establishment of the provincial ALR, which, in the lower Fraser River basin, originally covered an area of about 148 000 ha, or 8% of the region. It has subsequently been reduced to about 140 000 ha, an average decline of approximately 500 ha/year (B.C. Agricultural Land Commission 1989).

Over 60% of the land in the ALR is currently being farmed. Agricultural use has intensified in the past decade, with significant increases in high-value specialty crops such as berry fruits, mushrooms, and greenhouse production (Runka 1990).

In addition to actual land-use conversion, there are growing pressures upon agriculture from adjacent uses, such as recreation and suburban residential development. Some farm practices, such as manure spreading and pesticide applications, can create friction between farmers and their nonfarm neighbours.

Sustainable agriculture depends on maintaining the quality and productivity of the soil. Intensive production, heavy fertilization, and limited conservation practices have contributed to a general decline in soil quality in the lower Fraser Valley (Standing Committee on Agriculture, Fisheries and Forestry 1984). Problems include erosion of fields exposed to winter rains, compaction of soil structure from cultivation under wet conditions, and subsidence of organic soils.

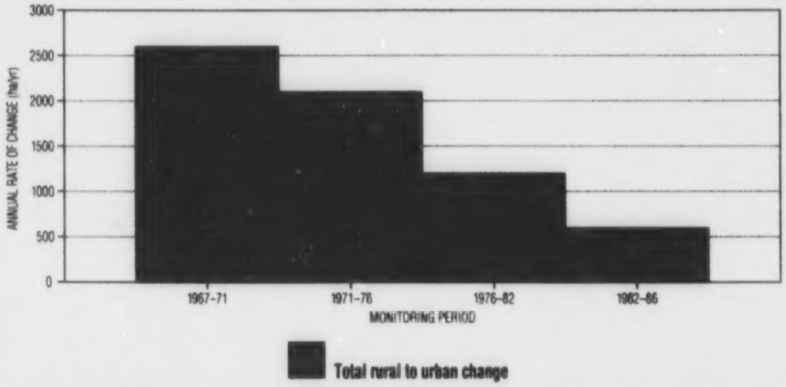
Overuse of nitrogen fertilizers has also contributed to increasing acidity in the soil. In some cases, applications of animal wastes from dairy, beef, pig, and poultry farms exceed the capacity of the land to absorb them, resulting in degradation of stream water and groundwater (Hutton 1987). In order to understand and address soil degradation problems more effectively, government agencies have carried out studies that focus on the highly erodible soils of the Matsqui and Langley uplands. In addition, government and industry are collaborating to develop a code of practice to control nutrient inputs from intensive agriculture.

Urban development and population growth

It is ironic the same attributes that have attracted people to live in the lower Fraser River basin — open spaces, natural beauty, recreational access to land and sea — are rapidly being consumed by the process of population growth. According to the Canada Year Book 1990 (Statistics Canada 1989), the population of the Census Metropolitan Area of Vancouver rose from about 1 million in 1971 to just over 1.4 million in 1987. The estimated population of the basin in 1990 was 1 711 915, reflecting an average increase of 2.4% per year since 1976 (B.C. Ministry of Finance and Corporate Relations 1990). By 2011, it is expected that the population will reach 2.27 million (B.C. Ministry of Finance and Corporate Relations 1989), of whom 84% will be migrants from elsewhere in Canada or from other countries (Greater Vancouver Regional District 1988*g*). The number of households in Greater Vancouver has increased from over 400 000 in 1976 to nearly 550 000 today and is expected to increase to 836 000 by the year 2011 (Greater Vancouver Regional District 1989*a*).

FIGURE 16.8

Rates of rural to urban land-use conversion in the Greater Vancouver region for four periods, 1967–86



Source: Redpath (1982); Environment Canada (1985); Moore (1990).

TABLE 16.7

Land in the lower Fraser River basin west of Rosedale Bridge (near Chilliwack) that is outside the Agricultural Land Reserve and available for urban development

Regional district	Area (ha)	Percentage
Greater Vancouver	12 231	54.6
Dewdney-Alouette	3 630	16.2
Central Fraser Valley	2 397	10.7
Fraser-Cheam	4 131	18.5
Total[a]	**22 389**	**100.0**

[a] For the most part, total does not include the following:
- redevelopment of existing areas.
- undeveloped capacity and infill within already designated urban areas.
- considerable lands designated rural in the Official Regional Plan update and Official Community plans.
- land generally east of Rosedale Bridge to Hope, and the Town of Hope itself.

Source: B.C. Agricultural Land Commission (1990).

The physiography of the region imposes some constraints on urban development. Less than half the region is habitable, the remainder being too mountainous. Consequently, most of the pressure for present and future growth has fallen on the fertile, relatively flat land south of the Fraser River. According to the Canada Land Use Monitoring Program, which reported on changes in land use in Greater Vancouver and portions of the Fraser Valley between 1967 and 1986, the rate of land conversion from rural to urban has declined from 26 km^2 annually between 1967 and 1971 to 6 km^2 annually between 1982 and 1986 (Redpath 1982; Environment Canada 1985; Moore 1990). Figure 16.8 illustrates the rates of rural to urban land conversion in the Greater Vancouver region for four periods between 1967 and 1986.

However, continued population growth and development pressures have raised major questions within the region regarding the long-term capacity for growth, the form and density of urban development, and the impact on environmental quality and other resource users. Pressures to develop agricultural lands, wetlands, foreshore areas, and productive forest lands continue to increase, and the issue of urban growth versus "the environment" is already evident in many land-use debates.

On the other hand, there appears to be ample opportunity for urban growth without infringing on the farmlands of the region. For example, a 1990 study by the Agricultural Land Commission (Table 16.7) identified 22 000 – 40 000 ha of land outside the ALR that was suitable for urban development, including approximately 18 000 ha in rural areas (B.C. Agricultural Land Commission 1990).

In response to this apparent contradiction, some local governments are encouraging the redevelopment of urban lands at higher densities and consider-ing the pros and cons of controlled growth. The struggle to define the appropriate structure and density of a "livable" region has been the focus of an extensive planning process by the GVRD. Clearly, the decisions that are taken within the next decade will have important implications for the state of the environment in the lower Fraser River basin.

Transportation

As population grows, so does traffic congestion and the demand for expansion of transportation services. In 1987, peak rush-hour automobile and transit trips in the GVRD totalled 168 900 and 37 500, respectively. By the year 2001, planners project that peak rush-hour auto trips will have risen by 31% and transit trips by 26% over present levels (Greater Vancouver Regional District 1989*b*).

In view of growing public awareness of the contribution of fossil fuels to air pollution and of the consumption of land for freeways and parking lots, it is clear that the present trend is unsustainable. Alternate fuels and forms of transportation and greater reliance on mass transit hold some hope, but use of such options must increase dramatically if acceptable environmental quality is to be maintained.

Similar questions arise in other sectors of transportation as well. With regard to air travel, a long-standing proposal to add a third runway at Vancouver Inter-

TABLE 16.8

Solid waste management facilities

Facility	Waste (t), 1988	Design capacity or remaining years
Landfills:		
Burns Bog	593 400	40 yrs
Port Mann	186 300	8 yrs
Coquitlam[a]	79 550	nd
Minnies Pit	13 000	8–20 yrs
Chilliwack	28 652	10–15 yrs
Kent[b]	469	10 yrs
Hope	4 500	0 yrs
Cottonwood[c]	24 486	closed 1989
Jackman Pit[c]	4 091	closed 1989
Valley[c]	36 888	closed 1989
Cache Creek	n/a	60 yrs @ 300 000 t/yr
Subtotal	**971 336**	
Incinerators:		
Burnaby[d]	171 680	235 000 t/yr
Kent[d]	7 830	7 830 t/yr
Subtotal	**179 510**	
Resource recovery:		
Coquitlam	2 500[e]	225 000 t/yr
Recycling	121 340	n/a
Total	**1 274 686**	

nd means no data; n/a means not applicable

[a] Handles ash from the Burnaby incinerator and transfer stations.

[b] Handles ash from the Kent incinerator.

[c] Closed in August 1989; refuse diverted to the Cache Creek landfill.

[d] Tonnage in 1988 is the *net* weight of refuse incinerated.

[e] Weight consists of recycled wastes; operations commenced in 1989.

Source: Greater Vancouver Regional District (1988*h*, 1988*i*).

national Airport was recently reviewed by an Environmental Assessment Review Panel. Deep-sea and coastal shipping are important activities on the lower Fraser, and port expansion has occurred at several sites over the past 15 years. Facilities at Roberts Bank were expanded in the early 1980s, resulting in the destruction of large areas of intertidal habitat. Other expansion projects have occurred on the main arm of the river at the Fraser Surrey and Fraser Richmond facilities.

Waste management

In a prosperous consumer society, large communities generate large quantities of garbage. The disposal of solid waste, including special and hazardous wastes, has become a major issue in the lower Fraser River basin.

Solid wastes

The current regional waste management system handles more than 1.27 million tonnes of domestic and commercial refuse per year (Greater Vancouver Regional District 1988*h*). This is an increase of 11% from 1982 to 1988 and excludes 500 000 t/year of debris from land clearing and demolition and 400 000 t of wood waste. Whether the disposal system can cope adequately if solid waste generation continues to increase at its present rate, or indeed whether present waste handling practices will be environmentally acceptable in the future, are questions that demand close attention.

At present, 76% of solid waste is disposed of in seven landfills. In addition, about 200 000 t of solid waste per year are trucked a distance of 340 km to a landfill at Cache Creek. A further 14% is incinerated at two incinerators, and 10% is recycled or otherwise recovered (see Table 16.8). Many of the older landfill sites, both active and inactive, are located close to the Fraser River, where they release toxic leachates as well as foul odours.

In 1988, recycling recovered about 121 000 t of material, and the current recycling action plan adopted by the GVRD aims to divert another 20% from the waste stream by the mid-1990s (McLaren Engineers 1989). With public and private sector support, and strong consumer interest, markets for recycled products are expanding. The anticipated opening of a de-inking plant within the next two years is expected to increase demand for, and availability of, recycled newsprint.

Nevertheless, solid waste disposal will likely remain a critical environmental issue within the region. Given the expected life of existing landfills and incinerators, and the projected growth in tonnage of solid waste to the year 2000, the region is faced with two options: a massive and successful program to reduce, reuse, or recycle up to 50% of solid waste; or construction of one or more disposal facilities, whether landfill, incineration, or other, in the face of probable, strong, public opposition.

Special wastes

At the other end of the waste spectrum from the recyclables are special wastes: substances that may be poisonous, infectious, chemically reactive, corrosive, flammable, carcinogenic (cancer-causing), or mutagenic (capable of inducing genetic mutations). About 80% of the estimated 74 000 t of such wastes produced annually in British Columbia originate in the lower Fraser River basin (B.C. Ministry of Environment 1983).

Special wastes can originate in households, hospitals, farms, laboratories, factories, and commercial enterprises. Depending not only on the substance, but also on the knowledge and conscientiousness of the user, they may be disposed of in landfills, dumped into sewers or storm drains, shipped out of province for disposal, recycled, or held in special storage facilities. In 1985, the B.C. Ministry of Environment identified some 385 companies in the lower Fraser River basin that had special waste disposal needs, and 26 priority sites at which special wastes were damaging the environment (B.C. Ministry of Environment 1985*b*).

Also classified as special waste is the fly ash — 8 000 t/year — that is generated by the solid waste incinerator in Burnaby. At present, this material is deposited in segregated cells in the Coquitlam landfill. All leachates from the landfill are conveyed from there to the Annacis Island sewage treatment plant for disposal. This is a temporary arrangement. The GVRD plans to have a more permanent method of treatment and disposal.

Another closely related concern is the accidental spillage of hazardous materials, such as gasoline, caustic soda, chlorine, sodium hydroxide, and a host of other potentially dangerous substances that are in common use. The main arteries for road or rail transport of these goods traverse densely populated neighbourhoods and environmentally sensitive areas throughout the lower Fraser River basin. An accidental spill could cause extensive environmental damage and pose a serious threat to public health and safety. Between 1983 and 1986, 128 accidental spills occurred, fortunately without serious consequences (Transportation of Dangerous Goods Study 1988).

Sustaining land resources

The foregoing notes on land use in the lower Fraser River basin underline the complex challenges facing decision-makers who must attempt to resolve issues and integrate conflicting demands. For land uses such as forestry, agriculture, recreation, and wildlife, a stable land base is critical; yet, rural resource lands in the region have been converted to urban uses at a rate of about 600 ha annually in recent years.

In recent years (1985–90) agricultural lands have been declining at a rate of 368 ha/year — a slower rate than in the 1960s and 1970s, but still significant. The contemporary definition of forest resources is broadening to such an extent that a philosophy of forest management dedicated solely to extracting the maximum sustainable volume of timber is no longer acceptable to a large proportion of the public. As the basin becomes more urbanized, "green spaces," including wildlife habitat, forested ravines, and environmentally sensitive areas, are all gaining importance in the public agenda.

What forms of urban development, transportation, waste disposal, resource development, and conservation will best preserve long-term environmental quality in the lower Fraser River basin? To what extent can growth continue without further depleting the natural resources of the region beyond recovery? There are critical choices to be made, choices that will determine whether present levels of environmental quality can be maintained over the long term in the lower Fraser River basin.

CHALLENGES FOR A SUSTAINABLE ENVIRONMENT

Clearly, the sustainability of environmental quality in the lower Fraser River basin faces major challenges. Will the current framework for environmental management and stewardship be adequate to channel the pressures of increasing population and development in constructive directions, while reversing trends in environmental degradation? In order to meet this challenge, several obstacles must first be addressed.

Multiple jurisdictions

More than 75 agencies — local, regional, provincial, and federal — have some degree of responsibility for managing land and water resources and human activities related to the maintenance of environmental quality. Each has its particular mandate, which may complement, overlap, or even contradict those of other agencies. With so many stakeholders, it can be very difficult to synchronize decisions and reach agreement on common goals for environmental protection.

Scientific uncertainty

Data on the state of the environment are often inadequate, being derived from short-term or localized studies on particular issues. With some notable exceptions, such as the 1985 GVRD air emissions inventory (Greater Vancouver Regional District 1988*a*), few studies have been designed to produce trend information.

The inadequacy of data is apparent in the uncertainties that surround decisions relating to the environment. Information is particularly lacking on long-term and cumulative effects of sublethal pollutant levels, and of incremental losses of habitat upon the productivity and viability of fish and wildlife species. The problem of uncertainty is particularly evident in the evaluation of water quality. Despite all the measurements taken in the Fraser River over the past decade, many scientists still feel their statistical information will not support firm conclusions about the overall state of water quality.

Management philosophy

Depending on their mandate and the disciplines in which their personnel are trained, different agencies may operate from fundamentally different perspectives. For example, whereas one organization may be devoted to the efficient harvesting of timber, another, with a different set of values, may be committed to the preservation of forest ecosystems. While one is required to manage a resource for optimal economic return, another may deal primarily with social values of the same resource, which do not necessarily lend themselves to economic analysis.

Another contrast is between a focus on regulation and enforcement, and a focus on treatment and prevention. The regulatory approach to pollution control concentrates on volume, composition, and the eventual fate of pollutants in the environment. It sets quality objectives and enforces control measures to ensure that they are not exceeded. In contrast, the source control approach aims to reduce or eliminate loadings through pretreatment and discharge treatment. Each of these approaches can play a role in resolving virtually every pollution problem; however, public opinion is tending to favour source control (i.e., avoidance of the problem at the front end) as a more reliable basis for environmental sustainability.

Management of growth

Population growth, urban development, and the environmental pressures that follow seem at times to expand faster than they can be managed. Urban runoff and industrial runoff have rendered Boundary Bay and many small streams unsuitable for fish and for certain recreational uses. Critical wildlife habitat is being lost to urban and rural development and resource extraction. Air quality improvements are being outstripped by the increased volume of automobile emissions. Water consumption and wastewater production are both rising faster than infrastructure can be upgraded. Solid waste management facilities are expected to reach their full capacity by the mid-1990s, even if the goal of recycling more refuse is successfully met.

Changing environmental values

Public awareness of the state of the environment in the lower Fraser River basin has never been higher. Events such as oil spills and conflicts between conservation and resource extraction interests have alerted residents to the vulnerability of the setting in which they live. More people are demanding that environmental concerns be explicitly recognized in formulating decisions and policies about the use of resources. This trend has been apparent in heated controversy and debate at public hearings on a variety of development proposals, and in the results of public opinion surveys, which rank concern for the environment as one of the top priorities.

Changes in social and cultural values related to the environment have major implications for resource managers. Higher public expectations imply that managers will need to adopt integrated, ecosystem approaches to the allocation and management of resources. Changing values may prompt increased action in areas such as sewage treatment, pollution monitoring and enforcement, damage prevention, and habitat conservation.

STEPS IN THE RIGHT DIRECTION

Over the past decade, resource management programs in the lower Fraser River basin have begun to reflect a new emphasis on environmental protection. Some examples are described below:

- *Agencies are cooperating in joint resource management activities by establishing coordinated policies, programs, and planning mechanisms to protect environmental quality.*

Most notably, the Fraser River Estuary Management Program administers programs for coordinated project review, area designation, water quality, waste management, fish and wildlife habitat, recreation, log management, navigation and dredging, and port and industrial development. A similar program is being considered for Burrard Inlet. Interagency cooperation is also evident in developing monitoring programs and research into environmental quality issues. The Department of Fisheries and Oceans and the B.C. Ministry of Environment, for example, have developed a fish habitat inventory and information system that groups and integrates potentially useful management information by watershed. The Fraser River Action Plan, identified in the federal government's Green Plan, provides an excellent opportunity to take steps towards sustainable development (Government of Canada 1990).

- *Resource management initiatives are cutting across political boundaries, in favour of regional and ecosystem approaches to problem solving.*

In one instance, the GVRD has initiated a liquid waste management plan to address the long-term problem of treating municipal wastes and runoff. A solid waste management program is under way, and the established air management plan already in progress may well be extended up the Fraser Valley. The Livable Region Strategy has been updated for the 1990s to provide goals for urban planning and development in Greater Vancouver (Greater Vancouver Regional District 1989*c*).

Farther up the valley, agencies are collaborating in the reclamation of Cheam Lake, near Chilliwack, and in establishing wildlife management areas where important wetlands and other natural features occur. At the international level, one priority under the Pacific Coast Joint Venture of the North American Waterfowl Management Plan is the acquisition of wetland areas in the Fraser delta.

- *Increasingly, agencies are designing and implementing policies and programs that lie beyond the limits of their traditional mandates, and which give more consideration to environmental and social values.*

In conjunction with the Department of Fisheries and Oceans, the North Fraser Harbour Commission has established an Environmental Management Plan for the North Fraser Harbour. It includes an innovative fish habitat banking program. In addition, the Vancouver Port Corporation has developed a marine recreation resource use plan for eastern Burrard Inlet and Indian Arm. Another example can be found in the environmental programs of Transport Canada's Transportation of Dangerous Goods Directorate.

Local and regional governments are beginning to respond to the need to manage growth. Currently, emphasis is on controlling and directing development towards areas of low environmental sensitivity, as well as away from prime agricultural lands. Individual municipalities are also establishing specific policies for environmental protection and natural drainage control and have acquired parks and recreational corridors that focus on the river and estuary.

- *Innovative designs are beginning to appear in specific development projects, recognizing environmental sensitivities and the need to protect and enhance the natural environment as a precondition to development.*

In recent years, a new imperative has emerged, requiring that proposed developments not only minimize impacts on and risks to the environment, but also respond more directly to natural attributes of the landscape. In some cases, developers are being required to improve on the current state of the environment by rehabilitating previously degraded sites or by enhancing natural, biophysical productivity. For example, designs for incorporating "ecostrips" into some types of dike upgrading and maintenance programs have been developed. Preservation of the Tsawwassen salt marsh, the largest of its type in the estuary, was also achieved through sensitive engineering design of flood protection works. The "no net loss" habitat policy of the Department of Fisheries and Oceans has also inspired various marsh creation and rehabilitation projects to offset the effects of proposed developments.

- *The importance of public involvement in decision-making is now formally acknowledged in most resource management initiatives, and public interest organizations are showing increasing leadership and initiative in promoting environmental awareness and undertaking environmentally responsible resource management activities.*

In the past, task forces and environmental review panels were created to deal with interagency review of large projects, including airports and port expansion, dredging and diking, double-tracking of railways, fuel storage, and the transport of dangerous goods. To varying degrees, these included programs for public involvement. Now, the activities of environmental conservation organizations have increased public awareness of, and interest in, environmental issues. Groups that have been consistently in the forefront in the lower Fraser River basin include the West Coast Environmental Law Association, the Society for the Promotion of Environmental Conservation, the Fraser River Coalition, Greenpeace, the United Fishermen and Allied Workers Union, the Outdoor Recreation Council of B.C., the B.C. Wildlife Federation, and the Federation of B.C. Naturalists.

Also, public interest groups have been active in promoting environmental protection and conservation. Community-based recycling programs, for example, grew from the dedicated efforts of local volunteer groups. Ducks Unlimited, the Nature Trust of B.C., and the Pacific Estuary Conservation Program have assisted in securing and/or rehabilitating wildlife habitat at various locations. Many local fish and wildlife clubs, along with the B.C. Wildlife Federation, help to implement government-sponsored initiatives such as the federal Salmonid Enhancement Program. School groups are also active in salmon enhancement projects, storm drain marking, and other community undertakings.

Although special interest groups have played a key role in environmental awareness and protection for some time, the general public has not shared their concern until recently. This is rapidly changing, however, as more information becomes available and the urgency of many environmental issues becomes more evident.

The level at which the environmental quality of the lower Fraser River basin will ultimately be sustained remains to be determined by future policies, practices, and events. At present, however, two factors provide grounds for optimism. One is the profound capacity of natural systems to heal themselves, if given sufficient respite from stress. The other is a passionate commitment by many people of the region to recover and maintain the environmental quality that they or their forebears came to the basin to enjoy.

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17

COURTESY OF CANADA CENTRE FOR REMOTE SENSING, ENERGY, MINES AND RESOURCES CANADA, OTTAWA

HIGHLIGHTS

The prairie grasslands region, also known as the prairie ecozone, is one of the most human-altered regions in Canada. Two of its native ecosystems, tall-grass prairie and plains fescue, have been almost eliminated. Less than 5% of the prairie grasslands region is protected at present.

■

Agriculture has produced the most drastic and extensive alteration of the prairies. About 87% of the prairie grasslands region is farmland, and about 44% is cropland.

■

The shift from grassland to grain cultivation on the prairies tends to increase losses of soil organic matter and plant nutrients; it is estimated that the original organic matter levels in prairie soils have been reduced 40–50%.

■

Prairie wetlands provide critical habitat for more than 50% of North America's waterfowl.

■

Relative to its area and population, the prairie ecozone is the native habitat of a disproportionate number of threatened and endangered species of Canadian wildlife.

■

The natural water systems have been extensively modified and intensively developed; reservoirs — for hydro and thermal power generation, irrigation projects, flood protection, and water management — have been developed on virtually every major river system in the grasslands region.

■

Although only about 2.4% of farmland is irrigated, irrigation accounts for 46% of water withdrawal; irrigation also accounts for 69% of total water consumption in the Prairie provinces.

■

Water quality is not getting significantly worse in most respects but is close to a minimal level at many locations, and current economic, social, and climatic trends may cause it to drop to an unacceptable level.

■

Economic development is at the limit of available water supplies in some basins in the Prairie provinces, and there are growing concerns in southern Alberta and Saskatchewan that increasing consumptive uses will prevent in-stream requirements of aquatic ecosystems from being met.

■

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> "… in the south our heritage of fragile native grasses has been virtually eradicated, leaving behind a barren landscape that in places sickens the heart to see. The beauty of the prairie landscape, a gift that belongs to all of us, is being destroyed, and even the wildlife finds it hard to survive."
>
> — Sharon Butala (1989)

INTRODUCTION

Until recently, a vast area of grasslands occupied much of central North America, extending south almost to the Gulf of Mexico, east to Lake Michigan, and west to the eastern slopes of the Rocky Mountains. The northernmost extension of the region occupies about 500 000 km^2 of what is now Alberta, Saskatchewan, and Manitoba (Fig. 17.1). This is about 5% of Canada's total area and 27% of the Prairie provinces.

Over the past century, the prairie grasslands region has been radically transformed, and only a small fraction of it remains in its native state. The killing of thousands of bison each year by European settlers was the first major recorded modification of the native prairie ecosystem. Since then, agriculture, resource development, and urbanization have had a variety of effects on the fertility of the soil, the quality of air, water, and wildlife habitat, and the availability of water in the region.

The prairie grasslands region, also known as the prairie ecozone, is one of the most endangered natural habitats in Canada (Gauthier and Henry 1989). This chapter first examines the current status of the various components of the prairie grasslands ecosystem, then focuses on the natural and human-caused stresses upon the ecosystem, particularly water resources. Finally, the ways in which governments and the public are responding to these stresses are discussed.

THE PRAIRIE ECOZONE

Grasslands occur wherever the environment is too arid for closed forests but humid enough for dense growth of smaller plants (Stewart and Tiessen 1990). The prairie ecozone developed after the retreat of the glaciers between 8 000 and 11 000 years ago, through the interaction of climate on geological deposits; its boundaries have been stable the last 2 500 years but its form has changed in the past 200 years due to human activity. The various components of the prairie ecozone — climate, vegetation, wildlife, soils, and water — interact in complex ways with each other and with the human systems superimposed on them.

Climate

The climate of the prairie grasslands region is determined by its location in the heart of North America, far from maritime influences. The Rocky Mountains to the west impede easy access of moisture-bearing winds from the Pacific. The result is a pronounced continental climate, subhumid to semiarid, with short, hot summers, long, cold winters, low levels of precipitation, and high evaporation. Although dry, cold air from the Arctic predominates in winter, periodic chinooks, or strong westerly winds that become warm and dry as they descend the Rocky Mountains, bring spring-like conditions to southern Alberta and, to a lesser extent, southern Saskatchewan, reducing snow cover and removing moisture from an already dry region.

Recurrent drought is inevitable across the region (Phillips 1990). Droughts for protracted periods can be expected to occur in the prairie grasslands about three times a century (Rowe 1990). The most southerly portions of the region experienced drought in the 1880s, the early 1920s, and the 1930s (Rowe 1990). The single driest year was 1961, and the 1980s rivalled the 1930s in terms of intensity and duration of the dry spell and areal extent of the drought (Phillips 1990).

Local droughts occur almost every year somewhere in the grasslands area (Jones 1991), and widespread droughts are common during the growing season (de Jong and Kachanoski 1987; Williams *et al.* 1988). In the driest parts of the region, soil moisture available to plants at planting time may be only 15–30% of the soil moisture-holding capacity (R. Raddatz, Environment Canada, personal communication). On the other hand, violent summer storms may bring rain in amounts that exceed the soil's capacity for absorption, leading to washouts in smaller river systems, towns, and cities (Paul 1984) and sometimes to the formation of transient ponds that can destroy crops (K. Jones, Environment Canada, personal communication). For crops, the timing of precipitation during the growing season is often as important as the amount. Drought can also have a devastating effect on wildlife, pastures, and livestock, as well as on the generation of electricity (Jones 1991).

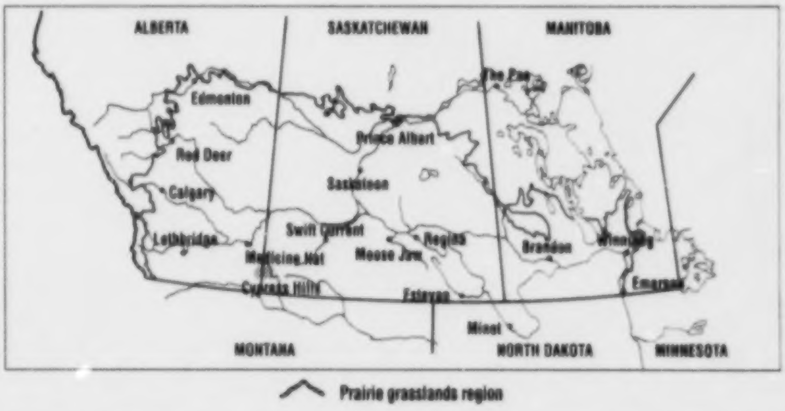
Vegetation

The vegetation of the prairie ecozone is fundamentally different from that of the forest ecozones, and native vegetation is fundamentally different from the agricultural crops that have largely replaced it. Native grasses and other vegetation are perennial, with up to 85% of their biomass invested in their extensive root system. Many grasses grow more slowly during the driest periods and reproduce largely through offshoots from their roots rather than from seeds (Rowe and Coupland 1984; Eisenberg 1989; Stewart and Tiessen 1990).

The vegetation patterns of the Prairie provinces are zonal, corresponding largely to climate and soil patterns (Laycock 1972). Accordingly, common geographical classifications (Rowe and Coupland 1984; Ecoregions Working Group 1989) differentiate among the following zones: (1) the most arid, mixed-grass prairie in southeastern Alberta and southwestern Saskatchewan; (2) a subhumid fescue prairie zone in the Alberta foothills and stretching north; and (3) a transitional northern zone of aspen parkland. Fescue prairie is often separated into fescue of the foothills and plains fescue, and some authors also recognize the driest region south of the Cypress Hills as separate short-grass prairie (Rowe and Coupland 1984). The boundaries are somewhat arbitrary, as fescue prairie occurs in aspen parkland and elevated areas such as Cypress Hills. All vegetation zones have been modified by human intervention: a tall-grass zone in south-central and southeastern Manitoba is almost completely cultivated (World Wildlife Fund Canada 1988), and the aspen parkland, the northern transition zone to the boreal forest, has expanded considerably southwards into previous grasslands since settlement effectively stopped prairie fires (Rowe and Coupland 1984).

FIGURE 17.1

The prairie grasslands region, also known as the prairie ecozone according to Environment Canada's terrestrial ecozones of Canada system of land classification



Source: Wiken (1986).

In arid zones, areas around bodies of water form habitats quite distinct from the surrounding drylands. Groves of cottonwood and other trees grow along rivers, forming diverse, highly productive habitats in river valleys (Rowe and Coupland 1984; World Wildlife Fund Canada 1988; Rood and Mahoney 1990). Prairie lakes, sloughs and marshes, and the surrounding uplands are areas of rich vegetation, which provide food, protective cover, and breeding and nesting space for a variety of birds, mammals, reptiles, and amphibians. One of the important functions of these wetlands is as breeding ground for over 50% of all North American waterfowl. Some wetlands — for example, spring potholes — may dry up after a few weeks, whereas others are permanent water bodies. Each type plays a crucial role at different stages of the life cycle of waterfowl, as does upland vegetation (Sugden 1984).

Wildlife

Prairie fauna, like prairie vegetation, have evolved to cope with extreme conditions. Many of the birds and mammals are migratory, and birds show unusually high geographic flexibility in the selection of breeding grounds or avoid breeding altogether in some seasons (McNicholl 1988). Prairie wetlands are responsible for more than 50% of all ducks born in North America and are essential resting and staging areas for migratory waterfowl (Gauthier and Henry 1989). River valleys provide sheltered habitats important to wildlife, especially during the harsh winter (Gauthier and Henry 1989).

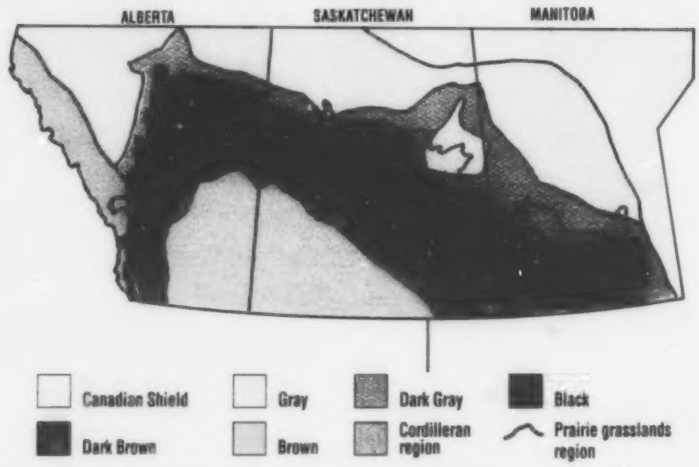
At one time, the North American prairies supported an estimated 50–60 million bison and 30–40 million pronghorn antelope, elk, and mule deer (Mitchell 1984; Arthur 1984), together with plains grizzlies and wolves. Today, the Canadian prairies are home to high numbers of threatened and endangered wildlife species (see Chapter 6).

Soils

The soil patterns of the grasslands reflect the influences of soil-forming factors — parent materials, slope and drainage, climate, and vegetation

FIGURE 17.2

Soil zones of the prairie grasslands region



Source: McGill *et al.* (1981).

(Laycock 1972). The combined influence of vegetation and climate results in several major soil zones. The combination of relatively low rainfall, high summer temperatures, and the chinook wind effect in southeastern Alberta and southwestern Saskatchewan results in a plant cover of relatively short, sparse grass (Peters *et al.* 1978). The soils, which have a light brown to brown surface layer, reflect these conditions. The surface colours are related to the organic content of the soil, and this arid zone is referred to as the Brown soil zone (Fig. 17.2).

East and north of the Brown soils, the climate is less arid and the vegetation taller. Consequently, soil surface layers become progressively darker because of the corresponding increase in the amount of organic matter that accumulates in the soil. These are the Dark Brown and Black soil zones. In the more moist and cooler locations, these zones are characterized by patches of trees and shrubs.

In the north and northeast sections of the area, the climate is more humid and cooler and forest replaces grasslands. The effects of climate, trees and shrubs, and the dominant kind of soil microorganisms result in the formation of soils with a grayish surface layer. This is the Gray soil zone.

In addition to the major soil zones, transitional belts between zones and "islands" of zonal soils also occur (Peters *et al.* 1978). These areas represent the effects of local variations in climate, vegetation, topography, drainage, and parent materials, or combinations of these factors. For example, Black, Dark Gray, and Gray soils occur in the grassland–forest transition area. Dark Brown, Black, and Gray soils occur on the Cypress Hills, where the higher elevations give a cooler, more moist climate than that of the lower plains occupied by Brown soils. Black soils may also occur on the north- and east-facing slopes of undulating areas in the northern portions of the Dark Brown soil zone.

The most productive soils in the region are the Black, Dark Gray, and Dark-Brown Chernozemic soils (Fig. 17.2) of the aspen parklands and the tall-grass and mixed-grass prairies (World Wildlife Fund Canada 1988; Ecoregions Working Group 1989). The soils were so fertile that they could be cultivated to produce crops practically without fertilizers for the first 20–30 years after being broken (Bentley and Leskiw 1985; Stewart and Tiessen 1990). The Brown Chernozemic soils of southwestern Saskatchewan and southeastern Alberta have a thinner surface layer and contain less organic matter. All soils in the prairie grasslands ecozone are susceptible to erosion, particularly when they are left bare as in summerfallow, on slopes, or where soil is sandy (Coote 1983; Agriculture Canada 1983; Dumanski *et al.* 1986).

Water

The Saskatchewan River system (basins 1–7, Fig. 17.3) drains the largest portion of the Canadian grasslands region. Waters of this drainage system rise on the eastern slopes of the Rocky Mountains in Alberta and Montana, flow eastwards into Saskatchewan and Manitoba, and eventually enter Lake Winnipeg.

At the southeastern boundary of the grasslands region, the Red River (basin 11, Fig. 17.3) rises in the United States and crosses northwards into Manitoba. The Red is joined by the waters of the Assiniboine River system (basins 8–10) at the City of Winnipeg, and their combined waters flow into Lake Winnipeg. Both of these major river systems receive runoff from highly variable sources in the grasslands.

Along the western half of the southern boundary of Canada's grasslands, the tributaries of the Missouri River, including the Milk River, rise outside the region in the foothills of the Rockies in Montana and in the Cypress Hills (basin 12, Fig. 17.3). The Milk River crosses the international boundary and eventually joins the Missouri River in the United States where it flows into the Gulf of Mexico.

The eastern slopes of the Rocky Mountains are the primary source of water for the Saskatchewan River basin. The headwaters of the main rivers contribute about 70% of the mean annual flow at The Pas, Manitoba, just downstream of the Saskatchewan–Manitoba border. Another 23% of the flow originates from tributaries just upstream from

The Pas, and only 7% is contributed directly by the plains region of the basin (Environment Canada 1989*b*, 1989*c*).

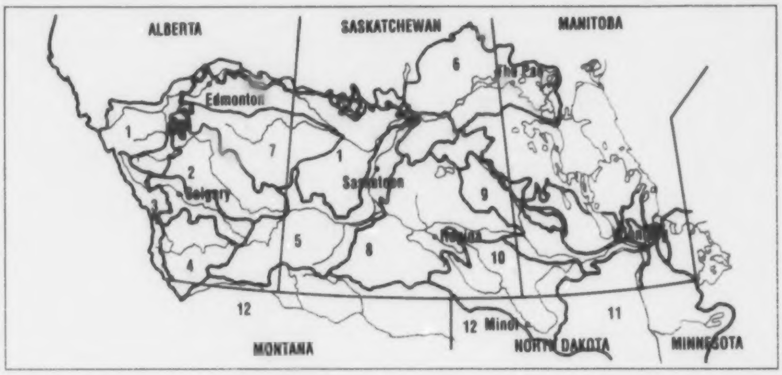
The combination of low annual precipitation, high evaporation, and large areas of poorly drained rolling, hummocky topography results in very low mean annual runoff from the plains. Precipitation mainly evaporates from the soil or is taken up by plants, with relatively little left over for surface runoff or interchange with groundwater systems. Thus, the lakes in the basins enlarge in wet years and shrink or disappear in dry years.

For rivers originating on the plains, annual flows and flows for any given month can vary dramatically, although typically 30–40% of the total runoff occurs in April. In contrast, rivers originating in the mountains produce less variable flows; usually 20–30% of the annual flows of these rivers occurs in June or July (Lane and Sykes 1982). Figure 17.4 shows the annual variation in flow for two rivers with similar volumes but different origins — the Bow River (Rocky Mountains) and Red River (plains).

Waters that originate in or flow across the prairies pick up high levels of nutrients, metals, minerals, salts, and sediments relative to mountain rivers. The quality of water is often a direct result of climatic and related factors, such as drought, flood, and timing of rainfalls. Nutrients, such as phosphorus and nitrogen, occur at high concentrations in prairie waters, because they are naturally abundant in regional soils. The abundance of these nutrients leads to eutrophication of lakes, reservoirs, sloughs, and some rivers. Blooms of algae, growth of aquatic weeds (macrophytes), strong odours, cloudy water, unsightly beaches, oxygen depletion, and periodic fish kills are usually associated with eutrophic waters. The Fishing Lakes in Saskatchewan's Qu'Appelle River valley, and even lakes that have not been significantly altered by human activity, typify this condition (data from Water Quality Branch, Inland Waters Directorate, Environment Canada, Regina).

FIGURE 17.3

River basins within the prairie grasslands region



1	North Saskatchewan	4	Oldman	7	Battle	10	Souris
2	Red Deer	5	South Saskatchewan	8	Qu'Appelle	11	Red
3	Bow	6	Saskatchewan	9	Assiniboine	12	Missouri

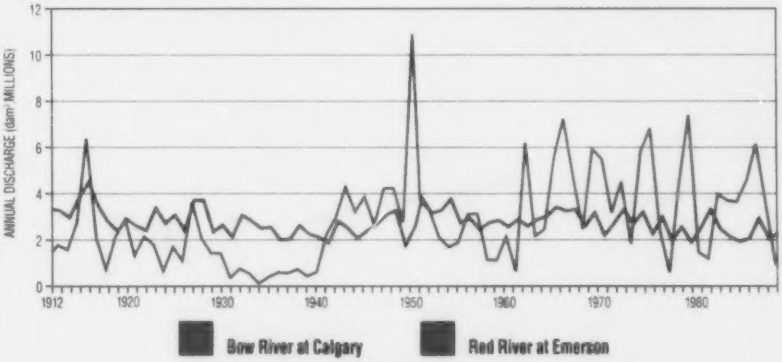
Prairie grasslands region **River basin**

Source: Environment Canada, Inland Waters Directorate, Western and Northern Region, Regina.

FIGURE 17.4

Comparison of a river that originates in the mountains (Bow River) and a river that originates on the plains (Red River) with similar annual volumes of flow

Rivers that originate on or flow long distances across the prairies acquire distinct characteristics, one of which is widely varying water levels.



Note: 1 dam³ = 1 cubic decametre = 1 000 m³. Mean annual discharge of Bow River at Calgary = 2.89 million cubic decametres. Mean annual discharge of Red River at Emerson = 3.02 million cubic decametres.

Source: Environment Canada (1989*b*, 1989*c*).

High concentrations of calcium, magnesium, and sodium sulphate and bicarbonate salts are typical of many waters in arid areas of the prairies. High rates of evaporation, low precipitation, and naturally saline groundwater flows contribute to the salt levels of prairie surface waters. In the winter, salinity can increase in the water of shallow lakes as a result of freezing because salts are excluded from ice and concentrate in the remaining water. Lakes that have no connection to the main stream system and therefore have an unreliable source of water for rejuvenation are typical on the prairies. Evaporation is high and inflows are low, resulting in very saline lakes, such as Old Wives Lake (a dry lake during the mid- to late 1980s) in Saskatchewan, Pakowki Lake in Alberta, and Rock Lake in Manitoba. Saline water bodies, although undesirable for nesting waterfowl and sports fish, are important staging areas for waterfowl and provide habitat for certain endangered species — for example, the Piping Plover, which nests on beaches next to salt or fresh water.

Suspended sediment often results from soil and riverbank erosion. High suspended sediment loads cause water to appear cloudy or turbid and can also increase the cost of municipal and industrial water treatment. Sediments contribute nutrients and metals and may also carry substances such as pesticides into a water body.

Rivers that receive snowmelt from the mountains have lower levels of nutrients, dissolved salts, and oxygen-consuming substances than those whose primary source of snowmelt is the prairie. For example, phosphorus and nitrogen levels are 10 times higher in the Souris and Red rivers than in the Bow and North Saskatchewan rivers in the foothills reaches (data from Environment Canada). Dissolved solids (salts) concentrations are more than twice as high in the prairie streams relative to stretches of rivers close to their sources in the mountains. As the mountain-source rivers flow across the prairie, they increasingly acquire prairie water quality characteristics.

HUMAN AND NATURAL STRESSES ON THE ECOSYSTEM

The earliest significant human stress on the prairies came from the demand of Europeans for bison, first as provisions for the northern fur traders (starting in

TABLE 17.1

Changes in agricultural land use and population in the prairie grasslands region, 1971–86

Parameter	Manitoba	Saskatchewan	Alberta	Prairie grasslands region
Area (ha)	7 400 456	28 533 284	16 254 233	52 187 973
Area of farmland (ha)				
1971	6 137 406	25 136 100	14 290 650	45 564 156
1986	6 076 336	25 213 180	14 104 623	45 394 139
% change	−1.00	0.31	−1.30	−0.37
Farmland as % of total region				
1971	83	88	88	87
1986	82	88	87	87
% change	−1.00	0.31	−1.30	−0.37
No. of farms				
1971	27 581	72 653	38 288	138 522
1986	21 274	59 855	34 465	115 594
% change	−22.87	−17.62	−9.98	−16.55
Average farm size (ha)				
1971	223	346	373	329
1986	286	421	409	393
% change	28.36	21.75	9.65	19.39
Cropland area (ha)				
1971	3 159 347	10 608 210	5 030 159	18 797 717
1986	3 844 218	12 665 926	6 339 742	22 849 887
% change	21.68	19.40	26.03	21.56
Improved pasture area (ha)				
1971	216 994	742 318	723 849	1 683 161
1986	195 037	791 377	771 928	1 758 342
% change	−10.12	6.61	6.64	4.47
Summerfallow area (ha)				
1971	916 683	6 495 432	2 247 874	9 659 989
1986	379 072	5 529 959	1 616 367	7 525 398
% change	−58.65	−14.86	−28.09	−22.10
Woodland area (ha)				
1971	225 126	314 306	181 576	721 007
1986	76 736	117 551	72 449	266 736
% change	−65.91	−62.60	−60.10	−63.01
Other land area[a] (ha)				
1971	1 619 257	6 975 834	6 107 192	14 702 283
1986	1 581 273	6 108 367	5 304 136	12 993 776
% change	−2.35	−12.44	−13.15	−11.62
Total population				
1971	843 945	875 925	1 347 685	3 067 555
1986	919 435	950 780	1 958 240	3 828 455
% change	8.95	8.55	45.30	24.80

[a] Other land includes areas such as barnyards, newly broken land that had not been seeded to a crop, uncultivated areas of native pasture or hay land, brush pasture, sloughs, marsh, and rocky land.

Source: Statistics Canada (1986).

Irrigated farmland in southern Alberta

Photo courtesy of Environment Canada, Inland Waters, Regina.

the 1780s), and then for buffalo robes and hides for the entire North American continent (Ray 1984; Arthur 1984). The killing of thousands of bison per year led to the virtual elimination of free-roaming bison by the 1880s. Increased hunting of pronghorn antelope, elk, and mule deer followed (Mitchell 1984).

The next major stress on the prairie grasslands came from agriculture, which started with the Selkirk Settlement in the Red River valley, Manitoba, in 1811. By 1931, 60% of the Canadian grasslands region was under cultivation; today this figure has risen to about 70% (Rowe and Coupland 1984). In 1986, an estimated 87% of the region was farmland, and about 44% of the total region was cropland (Statistics Canada 1986). The degree of annual cultivation of this area, known as the breadbasket of Canada, is high — possibly exceeding that of any other comparable region in the world (Coupland 1981, cited in Rowe 1990) — and it continues to expand incrementally (Rowe 1990). Agriculture is, in extent and impact, the dominant stress on this ecosystem today. Not only does it lead to alterations of the natural ecosystem, through land-use changes (Table 17.1) and irrigation, but it may contribute to its own demise through soil erosion, productivity loss, and salinization unless conservation practices are increased.

TABLE 17.2

Fraction of prairie still in its native state

Type of prairie	Fraction remaining (%)
Aspen parkland	<13
Tall-grass	<1
Rough fescue (foothills and Cypress Hills)	20–27
Plains fescue	1–5
Mixed-grass	24

Source: J.T. Romo, University of Saskatchewan, personal communication; E. Driver, Environment Canada, personal communication.

Urbanization of the prairie grasslands region is also a stress on the ecosystem. In 1986, about 3.8 million people, or 15% of Canada's population, lived in the prairie grasslands region, an increase of almost 25% from 1971 (see Table 17.1). All the major urban centres (greater than 100 000 population) of the Prairie provinces — Edmonton, Calgary, Saskatoon, Regina, and Winnipeg — are located in the grasslands region. One consequence of the rapid urban growth experienced by the Prairie provinces between 1966 and 1986 has been the conversion of rural land to urban uses. During this period, one-quarter (73 350 ha) of the rural land urbanized by Canadian cities with populations over 25 000 — to the point where the land is no longer capable of renewable resource production — was in the Prairie provinces. Alberta alone converted 51 691 ha (17%) of the total 301 440 ha of rural land urbanized around 70 Canadian cities of more than 25 000 population (Warren *et al.* 1989).

Stresses on the ecosystem from urban centres include the inadequate disposal of municipal sewage and industrial wastes, which brings problems of water pollution, and urban transport, space heating, and other fossil fuel combustion, which cause localized air pollution. Added to this are the problems of the urban–rural fringe, where outlying suburban developments have no access to municipal water distribution and sewage collection systems and, as a result, have a high density of septic tanks and wells.

A third contributing factor to stress on the prairie grasslands region has been the industrialization of the region in the 20th century. Resource development in the grasslands began with coal mining around the turn of the century. Oil and gas production started in the 1930s and 1940s, and potash mining in Saskatchewan began in the 1950s. Although the region is not heavily industrialized, some industries contribute to deteriorating air and water quality.

In addition to human-caused stresses, the prairie ecozone is subject to natural stresses, such as floods and droughts. In this section, the changes that have been occurring as a result of these various human-caused and natural stresses are described briefly.

Loss of habitat and wildlife

About 70% of native prairie has been tilled, and much of the remainder is used for grazing, sometimes to the point of overgrazing (Rowe and Coupland 1984). A high cost has been paid in terms of reduced soil productivity and loss of habitat, biodiversity, and wildlife populations. Two native types of prairie, tall-grass prairie and plains fescue, have been almost eliminated in Canada (Table 17.2). One of the last sites of tall-grass prairie, the St. James Living Prairie Museum, is found within a Winnipeg city park. Most of what remains of native prairie is considered marginal for cultivation and is under considerable stress from grazing.

Another threatened habitat is the riparian (streamside) vegetation along river valleys in the western prairies, primarily along the streams and rivers of the South Saskatchewan River basin. These valleys provide spectacular, diverse habitats for flora and fauna in the otherwise arid landscape and are also potential migration corridors for many species. In streams in southern Alberta, from which water is withdrawn primarily for irrigation, the remaining flow is often insufficient for riparian vegetation. Cottonwoods downstream from the St. Mary Dam have declined by 50% in 20 years and may be in irreversible decline; they also show signs of decline below the nearby Waterton Dam. The future of the cottonwoods downstream from the Oldman Dam will likely be decided by the future distribution of water between irrigation and streamflow (S. Rood, University of Lethbridge, personal communication).

Prairie wetland provides critical habitat for more than 50% of North America's waterfowl (see Chapter 26). The human impact on wetlands is difficult to quantify because the number of wetlands fluctuates dramatically between wet and dry years. Between 1.6 and 7.1 million wetlands have been reported for the same month in different years, the numbers correlating closely with common drought indices (Sugden 1984; K. Jones, Environment Canada, personal communication). Many wetlands also last only for part of the season. Nevertheless, a 1980 estimate placed losses of wetlands at 1.2 million hectares (Sugden 1984), and statistical analysis found an overall decrease of 22% in the number of ponds since 1955, whose average number over the last 10 years was 2.8 million (Dickson 1989; Caswell 1990). Depending on a number of factors, including survey techniques, time frame, and study area, estimates of loss of original prairie wetlands range from 40% (Gauthier and Henry 1989) to 71% (Environment Canada 1986). The number of ponds is not the only important factor in waterfowl habitat. Waterfowl require a variety of wetland habitats (Sugden 1984) and upland vegetation for nesting cover. Vegetation at many wetland margins has been affected by clearing, grazing, haying, and cultivation. In 1990, an estimated 30% of wetland basins and 82% of wetland margins had been affected by agricultural practices (Caswell 1990).

One of the earliest changes in prairie fauna following settlement was the disappearance of bison and their predators (plains grizzlies and wolves) and the drastic reduction in other large ungulates (Arthur 1984; Mitchell 1984). Today, there are no free-ranging bison in grasslands, and about 28 000 pronghorn antelope survive in mixed prairie in Alberta and Saskatchewan (Environment Canada 1983). Domestic cattle are now the dominant ungulate. About 4 400 bison remain in six national parks at the edges of the prairies, most of them in Wood Buffalo National Park outside the prairie grasslands (B. Beswick and M. Falk, Environment Canada, personal communication). Wolves are found in some of the same parks and in the foothills (Carbyn 1984). Birds of prey, coyotes, foxes, and a few other small mammals are now the top prairie predators.

Some ungulates, notably the white-tailed deer, have extended their pre-European range to include the Canadian prairies. They flourish in agricultural areas and are able to co-exist with people. There are some 100 000 such deer in the Manitoba part of the region alone. They are, in fact, a problem in the vicinity of Winnipeg International Airport, to the extent that some have been captured and removed to rural areas (W.J. Carlyle, University of Winnipeg, personal communication).

It has been stated that the loss of habitat is the most critical issue facing prairie wildlife (Gauthier and Henry 1989) and that, relative to its area and population, a disproportionate number of threatened and endangered wildlife species inhabit the prairie ecozone (Burnett *et al.* 1989). At least four vertebrate species (plains grizzly, swift fox, black-footed ferret, and Greater Prairie-Chicken) have been extirpated from the area. The Committee on the Status of Endangered Wildlife in Canada has listed five others (Peregrine Falcon *anatum* race, Mountain Plover, Piping Plover, Whooping Crane, and Eskimo Curlew) as endangered.

The threatened and endangered status of wildlife species is at least in part due to the insufficient attention paid to critical areas for wildlife in the prairie grasslands region. Hedges and wetland willows have been removed to allow easier cultivation, fields have been tilled to the edges of sloughs, uplands around wetlands have been hayed or grazed, riparian vegetation has been harvested for wood, and wetlands have been drained and ploughed. The result has been a drastic reduction in breeding and nesting spaces and an increase in exposure to predators, weather, farm chemicals, and the direct effects of equipment used in working the fields.

Farm and field shelterbelts have been established throughout the prairies. In some areas, this has produced a more treed landscape than was found at the time of European settlement. These "islands" of bushes and trees are havens for some types of birds and wildlife. The remaining areas of wildlife habitat, however, are often small and fragmented. Their contiguous range is often too small for many wild animals, and it is rare that migration corridors connect them. In addition, drift of pesticides from adjacent fields and direct disruption become increasingly likely each year (Sheehan *et al.* 1987).

Land degradation

Grasslands are easily disturbed ecosystems that are susceptible to soil erosion and desertification (Miller 1988), and the Canadian prairies are no exception. Because of the importance of agriculture in the prairie grasslands region, degradation of agricultural land is of particular concern.

As noted previously, the natural high fertility of grasslands soils initially enabled the production of crops with minimal use of fertilizers. In the early

1900s, the practice of cropping land in alternate years (summerfallowing) was introduced (Standing Committee on Agriculture, Fisheries and Forestry 1984) to conserve soil moisture for crops during the following year, to help regenerate soil fertility, and to control weeds. In the short term, fallowing is probably the only method that allows the soil to accumulate enough moisture to grow satisfactory commercial crops in some of the driest areas. In the long term, however, it is one of the major causes of soil erosion by wind and water, nutrient loss, and possibly human-induced salinization of nonirrigated lands. The total land in summerfallow as a percentage of the cultivated area (area of cropland plus area in summerfallow plus area in improved pasture) in the prairie grasslands region dropped from 32% in 1971 to 23% in 1986 (see Table 17.1).

Water and wind erosion are the most widespread soil degradation problems in Canada. In the Prairie provinces, it is estimated that water erosion affects 12% of the improved land area and has an annual on-farm economic impact of $155–$197 million (Dumanski *et al.* 1986).[1] Wind erosion is especially severe in southern Alberta and southern Saskatchewan. The estimated annual on-farm economic impact of wind erosion in the prairies is $213–$271 million (Dumanski *et al.* 1986).

Soil salinization is a natural process (primary salinity); it can also be induced through irrigation or cropping practices that disrupt natural groundwater regimes (secondary salinity). Salinization of dryland agricultural soils is a major problem in southern and central regions of Alberta and Saskatchewan, as well as scattered areas of Manitoba. It is estimated that about 3 million hectares of improved land in this area may be affected by secondary salinity. The economic impact of this salinity is estimated to be in the range of $104–$257 million annually (Dumanski *et al.* 1986) (see Chapter 9).

The shift from grassland to grain cultivation in the prairies tended to increase losses of soil organic matter and plant nutrients. It is estimated that the original organic matter levels in prairie soils have been reduced 40–50%. This represents a probable annual loss of about 112 000 t of nitrogen in the form of nitrate, and untold losses of phosphorus. It is estimated that this loss could be reduced by one-half with reductions in summerfallow based on good conservation objectives (Dumanski *et al.* 1986).

The risk of soil erosion on fallow land is considerably reduced when crop residue is left on the land, by windbreaks, crop rotations, or other techniques, or where living vegetation is recycled. In some cases, however, the only way to protect the soil is to leave it permanently vegetated. Usually such hard-to-protect land was marginal for production in the first place and may have been first cultivated because of inadequate knowledge of soil characteristics. More recently, farm support systems (e.g., crop insurance, grain delivery quotas) may have encouraged farming to continue on lands unsuited or marginal for arable agriculture (Girt 1990). Fortunately, such land can be restored to productive wildlife habitat by permanent revegetation. More detail on land degradation processes that affect the grasslands (e.g., dryland salinization and loss of organic matter) and on soil conservation and soil management practices is found in Chapter 9.

Air quality degradation and climatic change

The grasslands region has been traditionally regarded as having very clean air (Paul 1984). Although the absence of industrial contaminants in the [illegible] is one of the quality-of-life assets of the area, rapid urbanization and development of the fossil fuel industry over the past 35 years have raised some concerns (Paul 1984). Emissions of concern from the oil and gas industry are sulphur dioxide, oxides of nitrogen, and the by-products of flaring unwanted gases at the numerous production facilities. Modern technology has in part addressed these issues, although research continues to focus on the by-products of inefficient flaring. The acid-forming emissions from fossil-fuel-powered electricity generating stations, such as sulphur dioxide and oxides of nitrogen, can now be largely reduced by employing modern technology (see Chapter 24 for a discussion of the impact of acidic deposition).

Air quality in urban centres is at times affected by industrial activity such as secondary lead smelting (Winnipeg), oil and gas extraction (Lloydminster), and refining (Regina).

Human activities, such as the burning of fossil fuels, are adding to the Earth's natural greenhouse effect by increasing the atmospheric concentrations of greenhouse gases (e.g., chlorofluorocarbons, carbon dioxide, oxides of nitrogen, methane). Computer models suggest that if no major measures were taken to control greenhouse gas emissions, global concentrations of carbon dioxide and other greenhouse gases could be expected to double those of preindustrial periods before the middle of the next century (see Chapter 22 for more detailed information on climatic change).

How might increased concentrations of greenhouse gases affect the prairie grasslands? Estimates of changes in the prairies resulting from a doubling of carbon dioxide in the Earth's atmosphere as predicted by one computer model (H. Hengeveld, Environment Canada, personal communication) include an increase in average temperature (4.4°C in summer, 8.3°C in winter), a decrease in average soil moisture (-12.7% in summer, -2.3% in winter), and a change in average precipitation (-2.8% in summer, +12.1% in winter).

Other computer models predict a decrease in soil moisture, increased frequency and severity of drought, development of a semidesert in the southwestern grasslands, and a northward shift of the grasslands zone (Williams *et al.* 1988; Zoltai 1988; Rizzo and Wiken 1989; Stewart 1991). It should be kept in mind that confidence in regional estimates of climatic change is low, particularly for precipitation and soil moisture, values critical

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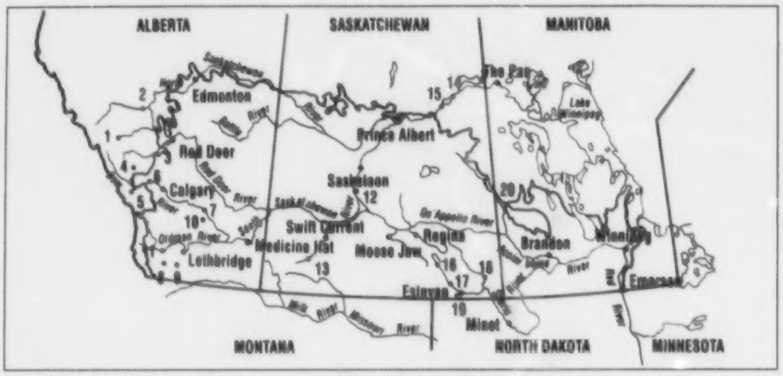
[1] For that particular study, the prairies included Manitoba, Saskatchewan, Alberta, and the British Columbia portion of the Peace River area.

FIGURE 17.5

Major dams in the prairie grasslands region



Prairie grasslands region

	North Saskatchewan River basin
1	Bighorn Dam
2	Brazeau Dam
	Red Deer River basin
3	Dickson Dam
	Bow River basin
4	Cascade Dam
5	Three Sisters Dam
6	Ghost Dam
7	Bassano Dam
	Oldman River basin
8	Waterton Dam
9	St. Mary Dam
10	Travers Dam
11	Oldman Dam

	South Saskatchewan River basin
12	Gardiner Dam
13	Duncairn Dam
	Saskatchewan River basin
14	E.B. Campbell Dam (Tobin Lake)
15	Francois-Finlay Dam (Codette Reservoir)
	Souris River basin
16	Weyburn Dam
17	Rafferty Dam
18	Alameda Dam
19	Boundary Reservoir
	Assiniboine River basin
20	Shellmouth Dam

Source: Environment Canada, Inland Waters Directorate, Western and Northern Region, Regina.

to the prairies (Intergovernmental Panel on Climate Change 1990). Furthermore, the rate of change may have an even larger impact than the change itself.

Water system modification

Water is the lifeline of the prairie grasslands. Therefore, an understanding of the ways in which people have adapted to its water supply and changed it to meet their needs is key to understanding this ecozone.

In the Prairie provinces as a whole, and in the grasslands region in particular, water systems have been extensively modified and intensively developed.

To capture water for delivery during times of drought and to prevent flooding during times of peak flows, reservoirs have been developed on virtually every major river system in the grasslands region. Saskatchewan has 53% of the approximately 770 dams in the Prairie provinces and 88% of the total reservoir storage capacity. Alberta has 40% and 9%, respectively. Manitoba accounts for 7% of the dams and 3% of the storage capacity (Agriculture Canada 1987). Figure 17.5 shows the largest dams in the region.

Another characteristic of water use in the grasslands is the number of dugouts (rectangular excavations varying in depth from 3 to 6 m, each with a storage capacity of 2 000–12 000 m^3 of water), wells, and small dams constructed for stock watering, irrigation, and general farm use. There are about 149 000 farms in the Prairie provinces and over 110 000 dugouts on farmland to capture spring runoff (Agriculture Canada 1986). During drought years, little or no spring runoff is available to recharge small dams and dugouts on the prairies. Farmers and ranchers are therefore forced to pump water into their dugouts from more reliable sources, such as rivers and lakes. Filling dugouts by pumping has become a means of providing more secure water sources for farm use.

The natural flow regimes of all major rivers in the grasslands region have been modified by reservoirs that store water for hydro and thermal power generation, irrigation projects, flood protection, water management, and interbasin transfers of water. In what way and to what extent the reservoir alters downstream flow depend on its purpose. Hydro power reservoirs tend to reduce spring and summer peak flows and to increase winter flows, as illustrated by the South Saskatchewan River at Saskatoon before and after construction of Gardiner Dam in 1968 (Fig. 17.6). In addition, river regulation for hydro development can result in substantial short-term variability of flow. For example, in 1979, on the Kananaskis River below Barrier Dam in Alberta, the highest daily discharge recorded for the entire year was 28.8 m^3/s on 19 May. The lowest discharge was recorded at 0.14 m^3/s four days later (Environment Canada 1989*b*).

Irrigation reservoirs tend to reduce downstream spring and summer peak flows. If the irrigation district is along the river, summer flows[2] may increase because snowmelt runoff is captured

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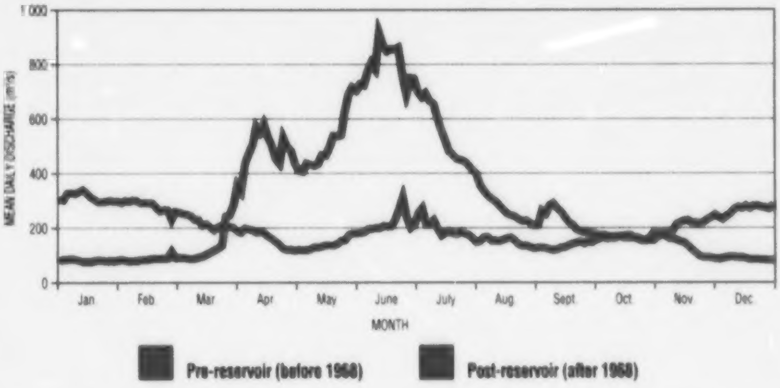
[2] In examining trends and developing water management schemes, careful distinction must be made between average flow and reliable flow. Where precipitation patterns are regular and consistent, the average and reliable flows are essentially the same. However, as Foster and Sewell (1981) pointed out, the flow one can reliably expect to find 9 years out of 10 on the prairies may be only 30% of the long-term average. The expectations of irrigators, hydroelectric system managers, and planners are very different, and the storage systems required would be much larger based on average flows rather than reliable flows. Any identifiable trends in the long-term average flows would be important, but trends in reliable flows should also be looked for.

FIGURE 17.8

The effects of reservoirs on downstream flows: South Saskatchewan River at Saskatoon

After the construction of the Gardiner Dam in 1968, the volume of water in the river in summer dropped and the volume in winter increased.



Source: Yuzyk (1987).

for later use when natural summer flows are low. Municipalities extract small amounts of water throughout the year, with higher demands during summer periods. The combined effect is a reduction in total annual flow volumes, depending on the demands. Annual flows in the South Saskatchewan River at Medicine Hat can be reduced by as much as 50% in low-flow years, primarily due to irrigation demands (Lane and Sykes 1982). Although reservoirs assist water management by making water available even during periods of low natural flow, evaporation from prairie reservoirs represents a major consumptive use of a scarce resource.

Reservoirs may moderate extremes in concentrations of many dissolved salts and may replenish dissolved oxygen during low-flow conditions. Some reservoirs, by virtue of the origin of their water, operational peculiarities, physical structure, and dimensions, may discharge water of poor oxygen content (anaerobic conditions) and high nutrients and biomass. Temperature regimes of downstream river reaches change with flow regulation, and earlier warming may promote earlier biological growth in the springtime. In the case of the Souris River in Manitoba, this will likely occur once the flow regime is modified by the Rafferty and Alameda reservoirs and associated hydrologic works (Environment Canada 1989*a*).

Although reservoirs improve the clarity of water in downstream areas, they also remove sediment from the downstream delta ecosystems. Since the construction of the E.B. Campbell Dam (on the Saskatchewan River at Tobin Lake) and Gardiner Dam (on the South Saskatchewan River at Lake Diefenbaker), the supply of suspended sediment to the Cumberland delta in Manitoba has been reduced by about 90%. The construction of the Rafferty–Alameda reservoirs in southeastern Saskatchewan would effectively trap sediments and possibly result in reduced phosphorus loading and reduced amount of sediment-transported pesticides downstream (Environment Canada 1989*a*).

Reservoirs can become traps for contaminated sediments. Tobin Lake traps particulates and associated pollutants from pulp mill operations, pesticides from agriculture, and other substances associated with upstream urbanization and industrialization (Warwick and Tisdale 1988). Sedimentation may negatively affect fish spawning areas. Mercury in lake and reservoir sediments may move into the aquatic food chain as a result of microbial action in the decomposing organic material. This is a natural process and is accelerated in newly created reservoirs. The mercury accumulates in fish and may render them unfit for human consumption. Recent improvements have been noted in the mercury levels in fish in a number of water bodies (e.g., Cookson Reservoir, North Saskatchewan River, Tobin Lake), although fish consumption guidelines still exist for many areas.

Reservoirs replace a natural riverine environment with a large, fluctuating aquatic environment, producing cyclical changes in the boundary between river and reservoir. Flora and fauna that have adapted to natural riverine conditions must now adapt to a new environment or perish.

The environmental impacts of reservoir construction are recognized. The public has voiced its interest in the assessment of consequences of projects such as the Rafferty–Alameda dams in southeastern Saskatchewan and the Oldman Dam in southern Alberta.

Water withdrawal

Of all human influences on water resources in this region, agriculture has the greatest effect. Agriculture can be practised in parts of the prairies only because of irrigation. Although only about 6 600 km^2 (2.4% of improved farmland) are irrigated, irrigation accounts for 46% of water withdrawal (Fig. 17.7). Thermal electric power accounts for a further 40% of the total water withdrawn in the Prairie provinces (6 050 000 dam^3).[3] Although water withdrawals for municipal and manufacturing uses are not as significant in terms of total withdrawals (about 14%), these uses are very significant in terms of the quality of the returning water.

Irrigation dominates all consumptive water uses, with 69% of the total consumption in the Prairie provinces (2 630 000 dam^3). On average, about 25% of water withdrawn for irrigation returns to surface waters. In comparison, thermal power plants withdraw

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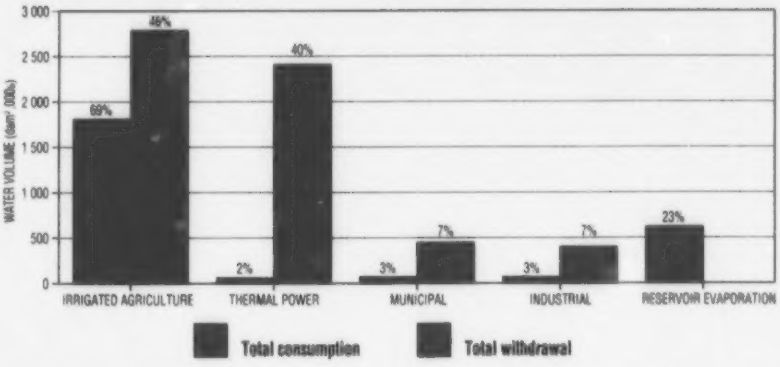
[3] 1 dam^3 = 1 cubic decametre = 1 000 m^3.

FIGURE 17.7

Water withdrawal and consumption in the Prairie provinces, 1986

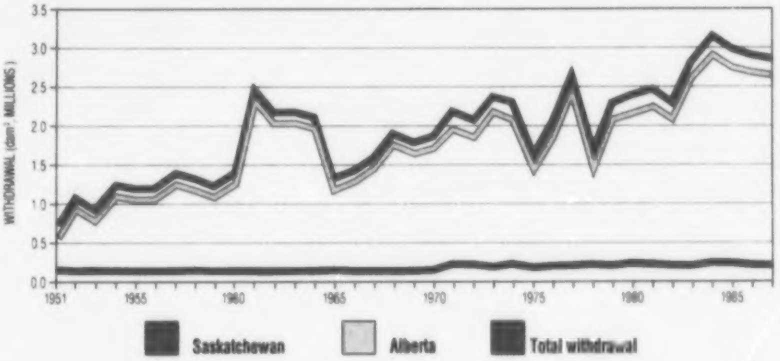


Source: Estimated by Environment Canada, Inland Waters Directorate, from data supplied by the Prairie Provinces Water Board.

FIGURE 17.8

Total water withdrawn for irrigation in Alberta and Saskatchewan, 1951–87

Most irrigated prairie farmland is in these two provinces.



Note: 1 dam³ = 1 cubic decametre = 1 000 m³

Source: Prairie Provinces Water Board (1990), updated by data from the Prairie Provinces Water Board for 1987.

large quantities of water, primarily for cooling, but return about 98% of it to surface waters. Evaporation from reservoirs, which store water mostly for irrigation and power generation, accounts for another 23% of water consumed. Consumption of water by other sectors (municipal and industrial) is minor (6%).

Since 1951, total irrigated area has increased by over 400%. Most of the irrigated farmland is in Alberta and Saskatchewan. The area that is privately irrigated has increased approximately 800% during this period and at a faster rate than the area served by district projects, i.e., those in organized districts using a common water supply. In 1986, private irrigation represented about 30% of the total irrigated area (Prairie Provinces Water Board 1990).

Water use in irrigation between 1951 and 1987 increased significantly, particularly in Alberta (Fig. 17.8), but fluctuated significantly from year to year, depending largely on precipitation. Generally, when growing season precipitation is high, demand for irrigation is low. Data for Manitoba are not included in Figure 17.8, as irrigation in that province is insignificant compared with that in Alberta and Saskatchewan.

Utilization of irrigation water has changed considerably since irrigation began on the prairies at the turn of the last century. Traditionally, most areas were irrigated by spring flooding or by a surface ditch or dike system, using water diverted directly from streams. Sprinkler systems are now more common, as these systems are more efficient and less labour-intensive and do not require land levelling. The result is a shift in the demand schedule from mainly spring use to a longer summer demand period. This has necessitated construction of storage works, especially if the irrigated areas are supplied from intermittent streams. These systems are also more efficient in terms of water use, with return flows generally being lower.

Thermal and hydro generating capacity in the Saskatchewan–Nelson river basin increased over 1 500% since 1951. The number of power plants increased from 26 to 40 over that period (Prairie Provinces Water Board 1990). Most of the hydro power (78%) is generated in Manitoba, downstream of the prairie grasslands region, on the Saskatchewan and Nelson rivers. Most of the thermal power is produced in Alberta, where use of water by these plants, mostly for cooling, has increased over 900% since 1951 (Fig. 17.9). Virtually every drop of water in the Saskatchewan–Nelson and Missouri river systems that is not consumed or evaporated will pass through at least one hydroelectric generating plant.

Urbanization places its own demands on water supply, although they are small relative to those of agriculture and thermal power generation. The severe and largely semiarid climate of the grasslands region has been, and continues to be, an overriding factor in defining the pattern of human settlement. Large areas of the grasslands region do not have ready access to the mountain-fed river systems that provide high-quality, reliable water supplies. In many of these areas, water supplies from prairie-originating streams and groundwater are unreliable or of poor quality.

Approximately one-third of the population of the Prairie provinces, mostly in rural areas, depends on groundwater for domestic use. Although reliance on groundwater by a large number of users is high, actual quantities withdrawn are relatively low. For example, in the South Saskatchewan River basin in Saskatchewan, use of underlying groundwater amounts to approximately 23 000 dam^3 per year (South Saskatchewan River Basin Study Board 1988). This compares with approximately 900 000 dam^3 of licensed allocation of the surface waters of the basin. The current level of groundwater use in this basin is substantially below the estimated annual yield of 450 000 dam^3. Relatively few irrigation projects rely on groundwater.

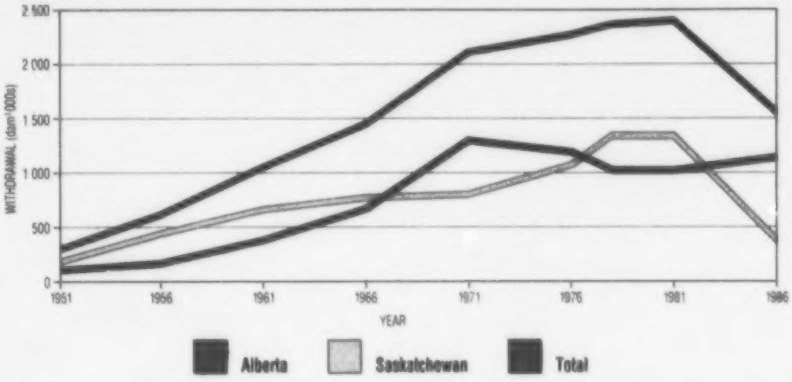
Although the region has a strong rural orientation, the population has been rapidly shifting from rural areas to both large and small urban centres. Rural residents made up about 53% of the population in 1951. This share is only 27% today. This increased urbanization has been accompanied by a generally rising trend in municipal water use, as indicated in Figure 17.10. The main implication of increasing municipal water use is the need to treat the water before and after use. Table 17.3 gives an indication of the array of uses of the grasslands' major rivers.

Water quality degradation

Agricultural, urban, and industrial activities are the primary human-induced factors influencing prairie water quality (Table 17.4). The effects are complex and often modified by the dominance of natural processes, but the final outcome — for example, eutrophication, increased levels of toxic chemicals, and increased fecal coliform counts — is the sum of individual actions and choices.

FIGURE 17.9

Water withdrawals by thermal power plants in the Prairie provinces, 1951–86

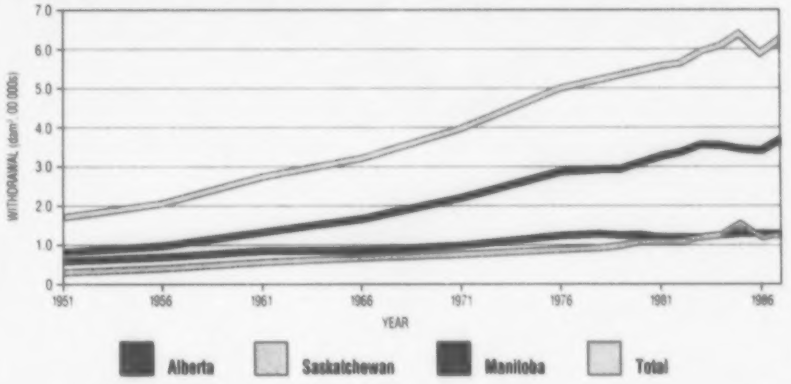


Note: 1 dam^3 = 1 cubic decametre = 1 000 m^3. Data for Manitoba not shown as withdrawals are insignificant compared with those in Alberta and Saskatchewan.

Source: Data provided by Prairie Provinces Water Board and Environment Canada.

FIGURE 17.10

Municipal water withdrawals in the Prairie provinces, 1951–87



Note: 1 dam^3 = 1 cubic decametre = 1 000 m^3.

Source: Prairie Provinces Water Board (1990), updated by data from the Prairie Provinces Water Board for 1987.

Agricultural activity

Conventional agriculture in the grasslands relies heavily on chemicals for pest control. The degree of environmental concern posed by a particular pesticide is determined by its persistence (i.e., ability to remain in a toxic form in the environment), rate of application, frequency of use, mobility (degree of retention by soil particles, solubility in water, and volatility to air), ability to be concentrated in living organisms (bioaccumulate), and tendency to be toxic to nontarget species (see Chapter 9). Although most pesticides, including herbicides and insecticides, either decompose rapidly or stay in the soil, some make their way to lakes and streams by runoff, erosion, spills, and aerial drift.

From 1984 to 1987, total sales of pesticides in the Prairie provinces declined from 27 440 t to 21 105 t. In general, the use of pesticides in the prairie

TABLE 17.3

Uses of the major rivers of the prairie grasslands region

River basin	Municipal	Agriculture (irrigation)	Power		Industrial
			Hydro	Thermal	
North Saskachewan River	****	*	****	****	****
Oldman River	***	****	*	*	**
Bow River	****	****	****	*	****
Red Deer River	**	****	*	**	**
South Saskatchewan River	****	****	****	**	***
Battle River	*	*	—	****	*
Souris River	****	*	—	****	*
Missouri River	*	***	*	**	*
Qu'Appelle River	****	**	—	—	***
Red River	*	*	—	*	***
Assiniboine River	*	**	—	**	*

Note: Recreational uses are not included because of their multiple and extensive characteristics.

* Relatively insignificant water use **** Significant water use — No present use.

Source: Environment Canada, Inland Waters Directorate, Western and Northern Region, Regina.

grasslands region is stable, with large annual fluctuations in tonnages for only a few pesticides, due to farm economics, competition between pesticide suppliers, and variations in pest numbers (Constable and Bharadia 1990).

The use of herbicides is an important issue in this region, as the three Prairie provinces use more than the rest of Canada combined (Constable and Bharadia 1990). This is not surprising, as more than three-quarters of the cultivated land in Canada is in the Prairie provinces. Sixty-six percent of the herbicide 2,4-D and 80% of all MCPA sold in Canada are used in the Prairie provinces. Residues of 2,4-D are occasionally detected in surface waters. The frequency of detection of the herbicide 2,4,5-T has diminished since 1979 as a result of reduced use and tighter restrictions. Measurable levels of the herbicides triallate, trifluralin, MCPA, diclofop-methyl, dicamba, glyphosate, atrazine, picloram, and bromoxynil are observed occasionally.

The use of organochlorine insecticides (the DDT family of compounds) has long been discontinued, except for one, lindane, which continues to be widely used to control flea beetles. Lindane is still detected extensively (Integrated Environments Ltd. 1989) and as frequently in regional waters as was reported for the 1970s (Gummer 1979). Low levels of organochlorine compounds have also been detected in several fish species (Beck 1986).

Agricultural practices are changing due to economic (market) factors, soil and water conservation requirements, and environmental concerns. The role of herbicides and insecticides will change in response to these. For example, the use of herbicides may increase where reduced or no tillage practices replace the practice of summerfallowing. The resulting benefits from reduced wind and water erosion and loss of organic matter will have to be carefully weighed against the environmental implications of increased herbicide use.

There still remains scientific uncertainty about the chronic and long-term effects of ongoing exposure of aquatic and human life to low levels of the pesticides (e.g., lindane and 2,4-D) found in most of the grassland water systems. Most of the new generation of pesticides break down rapidly in the environment and have less toxic by-products (Wong *et al.* 1989), but some organophosphorus insecticides, such as malathion, dimethoate, parathion, and methyl parathion, can be more toxic to aquatic life (Hauck 1990). Pesticide residues that persist in prairie waters exist at levels below those thought to be toxic to aquatic and human life.

Fertilizers, whose main ingredients are phosphorus and nitrogen, are used in conventional agriculture to replace plant nutrients removed through harvest (changes in fertilizer application in the Prairie provinces between 1971 and 1986 are indicated in Chapter 9). They can be carried with runoff from agricultural land into lakes and rivers, especially after intense storms. As nonpoint (diffuse) sources of pollution, such occurrences can have implications for basin management strategies for eutrophication control. The contamination by fertilizers of surface water is less a concern than the contamination of groundwater. Excess nitrogen, principally nitrate compounds, is readily transported through the root zone into the shallow aquifers. Improper irrigation practices can aggravate this situation by essentially flushing nitrates downward in the soil. In areas of intensive fertilizer use (e.g., southwestern Manitoba) and irrigation (e.g., southeastern Alberta), concentrations of nitrogen in the form of nitrate that occur in groundwater approach and sometimes exceed the Canadian drinking water guideline of 10 ppm (W. Nicholaichuk, Environment Canada, personal communication). Phosphorus, on the other hand, becomes attached to soil particles and is not prone to migrating downward through the soil except under unusual circumstances. It does, however, reach the water systems through movement of soil particles by erosion.

Drainage and seepage from irrigation, along with municipal treated waters and urban runoff, increase the salt levels in receiving water bodies. In recent years, significant improvements in irrigation practices have been realized. Extensive use of tile drainage, better water conservation practices, and more efficient delivery systems and irrigation units are just a few of the improvements. These, coupled with capturing return flows of irrigation water for reuse, such as at the Ducks Unlimited project at Luck Lake, Saskatchewan, have served to help protect the quality of water in the main stems of river systems. An increase of 2 ppm per year in salt levels in the Bow River near its mouth is partially due to the effect of return flows (HydroQual Consultants Inc. 1986). Statistical analyses of long-term trends indicate that dissolved solids in the Red, Souris, Oldman, and South Saskatchewan rivers have increased only slightly. In spite of improved irrigation practices, more widespread irrigation may have a cumulative effect, and increases in salt concentrations could be more pronounced in the future.

Water- and wind-eroded soil particles from farm fields can be carried into waterways to create such environmental problems as accumulation of silt, thus reducing channel capacity, affecting aquatic habitat and fish spawning areas, causing excessive plant growth, increasing levels of heavy metals, pesticides, and other toxic compounds, and reducing the recreational value of waterways.

The effect of livestock operations on water quality can be locally significant as a result of viruses, bacteria, and nutrient-laden runoff or groundwater seepages, as well as increases in sediment content. Effects can be minimized by keeping range cattle and feedlots distant from direct drainage systems.

TABLE 17.4

Primary factors influencing water quality

	Factors influencing water quality						
River basin	**Non-point pollution**	**Pesticide use**	**Irrigation**	**Livestock**	**Municipal effluent**	**Industrial effluent**	**Flow regulation**
Assiniboine	■	—		●	■	●	■
Battle	■	—		●	■		■
Bow	■	—	■	●	■	■	■
North Saskatchewan	—	—		●	■	■	●
Oldman	●	—	■	●	■	●	■
Missouri	●	—	●	●			■
Qu'Appelle	■	—	■	●	—	●	■
Red Deer (Alberta)	●	—	●	●	●		■
Red	■	—	●	●	■	●	—
Saskatchewan	●	—		●	●	●	■
Souris	—	—	●	●	■	■	■
South Saskatchewan	—	—	■	●	■	●	■

Legend

	Qualitative assessment	
Factor has:	**Local**	**Basin-wide**
Known major influence	■	■
Known minor influence	●	—
Potential major influence	■	■
Potential minor influence	●	—
No significant influence		

Example

■ : There are discharges of municipal wastewaters in the Assiniboine River basin that are known to have a major influence on basin-wide water quality.

Source: Environment Canada. Inland Waters Directorate, Water Quality Branch, Western and Northern Region, Regina.

Municipal centres

Municipalities adversely affect the quality of river waters with their sewage effluents and untreated urban runoff. Sewage effluents contribute large quantities of nutrients that accelerate the eutrophication process. Nutrient enrichment in prairie waters is as important to understand and control as is pesticide contamination (Fig. 17.11).

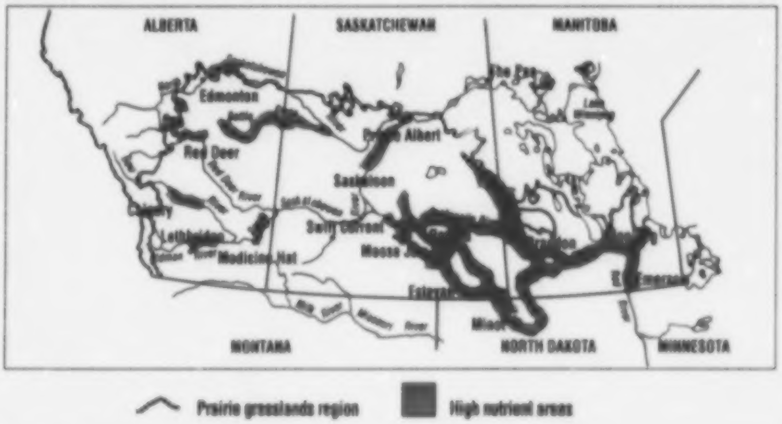
Ironically, nutrient enrichment can sometimes benefit the fishing industry. For example, the fishery downstream of Calgary is considerably more productive than upstream of Calgary. Recreational fishing on the Bow River below Calgary generates $4 million in direct and $11 million in indirect economic benefits to Alberta annually (Alberta Forestry, Lands and Wildlife 1988).

Although a reduction in phosphorus concentrations in effluent is a good management strategy for controlling enrichment in receiving rivers, a reduction in plant growth in response to lower nutrient loads is not always achieved. As algae and rooted plants are natural components of all aquatic ecosystems, we should not expect instant improvement of the water as a result of treatment. For example, phosphorus removal at Calgary after 1983 has resulted in a 70% reduction in the phosphorus concentration in the Bow River, but so far only slight decreases have been noted in weed growth in the river (Cross *et al.* 1984; Charlton and Bayne 1986; Chambers *et al.* 1989). Similarly, Regina has reduced its phosphorus contribution to the Qu'Appelle lakes by 80%, yet algae and weed growth remain prolific.

Sewage effluent can also cause the bacteriological quality of a river to deteriorate. Throughout the water systems in the grasslands region, the bacteriological quality of some river

FIGURE 17.11

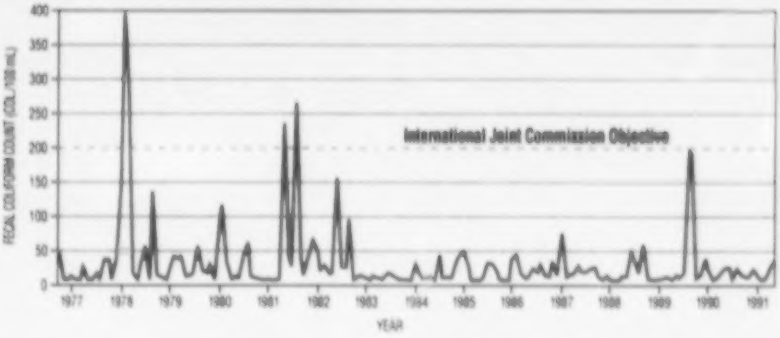
River reaches with nutrient enrichment problems in the prairie grasslands region



Source: Environment Canada, Inland Waters Directorate, Western and Northern Region, Regina.

FIGURE 17.12

Variability in fecal coliform counts for the Red River at the Manitoba international boundary, 1976–91



Source: International Red River Pollution Board (1990), updated by data from Environment Canada, Inland Waters Directorate, Western and Northern Region, Regina for 1991.

systems has improved significantly because of improved wastewater treatment. The Red River at the Manitoba international boundary, for example, has shown continued improvement (Fig. 17.12) since the early 1970s, when fecal coliform counts frequently exceeded desired objectives. Municipal treatment systems have been upgraded in the U.S. portion of the basin to meet water quality objectives. In Canada, Winnipeg continues to cause significant bacterial degradation as far as 30 km downstream at the city of Selkirk.

Inadequate treatment of municipal effluent can adversely affect the recreational potential of surface waters. The Red River downstream from Winnipeg has fecal coliform counts that frequently exceed the recreational guideline of 200 counts per 100 mL. Direct-contact recreational use of water immediately downstream of major municipalities, such as Edmonton, Calgary, Saskatoon, and Regina, is not recommended because of possible skin and other health-related ailments. Overloading of the Banff treatment plant during summer 1989 created a potential health risk to those using the Bow River for water-based recreation (H. Block, Environment Canada, personal communication). Mitigation measures were taken by the Canadian Parks Service, and a new treatment plant, under construction at the time, came on-stream several months later.

Humans generate large quantities of waste. The traditional method of waste disposal has been on land. Those disposal sites located near groundwater or surface water pose a threat to the nearby aquatic environment. In the early 1980s, as part of a national program, Environment Canada, in cooperation with each of the Prairie provinces, initiated a project to identify land disposal sites. At that time, 3 236 land disposal sites were identified in the Prairie provinces; 2 193 were active and 1 043 inactive. The breakdown by province, of active and inactive sites, respectively, was Alberta 705 and 447, Saskatchewan 958 and 366, and Manitoba 530 and 230 (I.D. Systems Ltd. 1982; MacLaren Plansearch 1982; Dillon Consulting Engineers and Planners 1983). The majority of the sites in all three provinces were municipal. Although a smaller number of the sites were industrial, these have particular relevance in terms of potential danger to human health and damage to the environment, due to the generally more toxic nature of the wastes.

Industrial activity

Individual industries have mostly localized effects on water quality, and these effects are less significant than the effects of agricultural and municipal activities. The cumulative impact of all industries on water quality is not known.

The oil and gas production industry operates in each of the three Prairie provinces, with the vast majority of production taking place in Alberta and Saskatchewan. Petrochemical processing facilities are located in both Alberta and Saskatchewan, in association with the oil and gas industry. Included in this sector are petroleum refineries, heavy oil upgraders, and secondary industries manufacturing petrochemical products.

These industries produce significant volumes of contaminated water, most of which is returned to underground formations by deep-well injection. Research and monitoring continue to ensure surface water and groundwater supplies are not at risk. In addition, federal regulations apply to discharges of oil and grease, total suspended solids, phenol, sulphides, and ammonia at refineries. The annual combined loadings from these refineries for the years 1982–88 indicate higher loadings in 1988 for all these substances, except for ammonia and sulphides (Environment Canada 1989*d*); these higher loadings are attributed to two new refineries. The substances in the liquid effluents from these refineries have remained in compliance with federal regulations for average monthly emissions since 1982. In addition to discharges in liquid effluents, oily sand or sludge has historically been spread on roads and around wellheads. The large volumes of this waste, and concern over its potential to pollute local streams, rivers, and lakes, have encouraged the testing of alternatives, such as land farming the wastes and recovering the oil from the sludge.

The most important industrial-related water quality contaminant problems to come to light in the grasslands during the late 1980s relate to abandoned industrial sites (O'Connor Associates Environmental Inc. 1989). For example, in Calgary, concern remains about wood preservatives and other organic contaminants leaching into the Bow River and groundwater systems. Expensive remedial action to clean up the site and control the problem has begun (Golder Associates Ltd. 1990).

Electricity is produced on the prairies at either hydro-powered or fossil-fuel-powered generating stations. Both options require water reservoirs, which have both positive and negative environmental impacts, as described earlier in this chapter.

The environmental concerns associated with potash mining relate primarily to the mine tailings. Common salt, an undesirable by-product, is discarded in tailings piles near the mines. It may enter into the surface water and groundwater or be blown into the atmosphere (Kupsch 1984). Mitigative measures have been taken to control these problems. Industrial activity is discussed in more detail in Chapter 14.

Floods and droughts

Flood flows in the prairies are common and unpredictable, making streamflow forecasting difficult. Floods usually result from one or some combination of natural conditions, such as rapid snowmelt, ice jams, or intense rainfall. Human activities, such as urbanization and agricultural drainage, can significantly alter flood peaks, particularly in small watersheds.

Severe floods may affect entire communities on the prairies. Short-duration annual spring flooding can be beneficial to forage production and to the creation and maintenance of riverine habitat. However, severe floods may result in significant damage to property and loss of life.

Of particular significance are the floods on the Red River, which can affect vast areas of the Red River valley and the City of Winnipeg. In 1950, 8 200 homes and 1 600 km^2 of land were flooded, and more than 65 000 people were evacuated (Royal Commission on Flood Cost Benefit 1958).

The construction of the Red River Floodway around Winnipeg, the Assiniboine River diversion to Lake Manitoba, and dikes in many Red River valley communities have alleviated much of the threat of flooding of urban areas, but flooding of agricultural land is still common.

Prairie streams regularly have periods of low flows. Some streams flow only during the spring, whereas others flow throughout the year as a result of the release of water from lakes, reservoirs, and groundwater. Widespread droughts have been recorded on the prairies during the 1880s, the early 1890s, the 1930s, the early 1960s, 1976–77, and the 1980s. The Bow River, used as an indicator of runoff from the Rocky Mountains, had less than the long-term (75-year) average runoff in 8 of the last 10 years and 14 of the last 20 years (Environment Canada 1989*b*).

The impact of drought can be severe locally, regionally, or nationally. For example, the loss from the 1984–85 prairie drought to the Canadian economy is estimated at $1.1 billion, in terms of reduced gross domestic product (Fautley *et al.* 1986), or about twice the annual losses due to soil degradation as a result of poor farming practices. Reduced export sales and increased operating costs of hydroelectric power production in Manitoba as a result of the 1988 drought are valued at nearly $100 million.

Prolonged periods of low flows for prairie streams have serious implications for disposal of liquid wastes and for municipal, industrial, and irrigation supplies. The effects of low-flow periods are mitigated to some degree by the construction of storage reservoirs, the pumping of surface water to areas where it is most needed, and the extraction of water from groundwater sources.

SOCIETY'S RESPONSE

Society is becoming increasingly aware of the importance of a healthy environment, from both economic and quality-of-life points of view. Soil, water, and air quality degradation, water availability concerns, and concerns for the preservation of wetlands and natural grasslands are all signals and signposts of change. Continued vigilance and resource management action are needed to protect the grasslands resource base and environmental heritage of the prairie grasslands region for future generations.

Land and wildlife conservation

In recent years, an increasing awareness of the social, economic, and intrinsic values of native prairie ecosystems has evolved. Consequently, numerous conservation, mitigative, and protective programs have been initiated or are being considered in Canada's prairie grasslands region.

In order to conserve and protect species and ecosystems, a network of protected areas has been established across Canada (see Chapter 7). Protected areas fulfill a variety of functions, including (1) preservation of habitat, wildlife, and integral ecosystems; (2) public education; (3) tourism; and (4) recreation. In the Canadian prairies, the protection of remaining habitat and ecosystems is vitally important (World Wildlife Fund Canada 1988).

A major concern is the conservation of prairie grasslands, the subject of the Prairie Conservation Action Plan. At present, less than 5% of grasslands are protected, including Grasslands National Park, which is still at the pre-establishment (land acquisition) stage. This park, in mixed-grass prairie in Saskatchewan, will eventually consist of two separate blocks, totalling about 900 km^2. The area contains many prairie species, is the last area where the black-tailed prairie dog is still found in Canada, and would be one of the few suitable habitats for the reintroduction of the black-footed ferret. The largest areas of relatively undisturbed prairie habitat, however, are located on three military bases: Suffield (mixed-grass) and Wainwright (aspen parkland), in Alberta; and Shilo (aspen parkland) in Manitoba (World Wildlife Fund Canada 1988) (see Chapter 7).

An early signal of public concern for the value of the prairie ecozone came with its identification as an area of international significance for conservation in the World Conservation Strategy of 1980 (World Wildlife Fund Canada 1988). Other significant events were the publication of the report "Soil at risk" on soil conservation (Standing Committee on Agriculture, Fisheries and Forestry 1984) and three major new initiatives for prairie conservation: the signing of the Canada – United States agreement respecting the North American Waterfowl Management Plan (United States Department of the Interior/Environment Canada 1986), the release by the World Wildlife Fund of the Prairie Conservation Action Plan (World Wildlife Fund Canada 1988) and its subsequent endorsement by the governments of the three Prairie provinces, and the national soil and water accords concluded between the federal and provincial governments in 1989.

These programs differ in emphasis and agencies involved, but all recognize the link between environmental quality, habitat protection, soil conservation, and sustainable agriculture. The relationship between these issues and agricultural economics and policies is also beginning to be recognized (Girt 1990). Several programs, particularly the Prairie Habitat Joint Venture (the prairie component of the North American Waterfowl Management Plan) and the National Soil Conservation Program, emphasize education, demonstrations, and technology transfer for the farming community. These latter two and several provincial programs provide considerable financial compensation for conservation practices for limited periods of time. It is expected, and in fact is key to the success of such programs, that after the end of financial support, conservation practices will have proven economically and socially superior and will spread by example.

The North American Waterfowl Management Plan focuses on conservation of waterfowl habitat and has a considerable involvement of hunting groups, whereas the primary goal of the Prairie Conservation Action Plan is the preservation of areas of native grasslands, parklands, and riverine habitats. There are also several provincial programs with similar aims. The National Soil Conservation Program promotes practices that conserve soil and sustain long-term agricultural productivity. This three-year program, instituted in 1988, encourages the conversion of marginal agricultural lands to permanent cover and the creation of shelterbelts. Further information on programs for soil conservation and habitat is found in Chapter 26.

Urban landscape has often been forgotten as potential habitat; in fact, it contains significant areas where plants and even wildlife find protection. The federal – provincial Flood Damage Reduction Program in the three Prairie provinces has promoted keeping areas undeveloped near rivers that are at high risk of flooding and preserving them for their ecological value rather than exposing human habitation to flood damage. Urban centres have also taken action to set aside valleys and other urban landscapes for habitat preservation. Over 70 years ago, the City of Edmonton set aside its Whitemud River valley (a parkland ravine) for protection, and one of the last tall-grass prairie sites is preserved within the City of Winnipeg (St. James Living Prairie Museum) (Metcalfe 1985; World Wildlife Fund Canada 1988). Another prairie grass site is in Calgary (Nose Hill, a fescue prairie site), and the establishment of grassland sites within other urban centres (e.g., Saskatoon and Wainwright) is under discussion (S. Rowe, University of Saskatchewan, personal communication; G. Holroyd, Environment Canada, personal communication; H. Trefry, Environment Canada, personal communication). The only successful introduction (or reintroduction) of Peregrine Falcons in the Prairie provinces has occurred in cities (McNicholl 1988). Such sites within urban centres are small sanctuaries for prairie ecosystems, including animals, and at the same time provide some of the best opportunities for educating and increasing the awareness of the general public.

Water management

Conflicts between water uses, particularly between in-stream uses and irrigation, have become a growing concern in southern Alberta and Saskatchewan. The large water withdrawals for irrigation from the Oldman, Bow, and South Saskatchewan rivers have reduced flows to such an extent that the survival of fish at times has been placed at risk, especially during drought periods. Water management agencies are expected to place greater emphasis on developing river flow and water quality objectives and standards that will ensure the safety of fish and other aquatic life. A central water management issue on the prairies is the allocation and management of a limited supply of water among uses so as to minimize the effects of one use on other uses and maximize the return to society.

Balancing supply with demand

The basic water management problem in the grasslands is allocating a relatively scarce resource among various uses, each with different quantity and quality requirements, and each use in turn affecting the quality and quantity of water. The provinces, in concert with the federal government, have developed river basin management plans and water data bases to assist in decision-making on the operation of dams and reservoirs to meet the range of demands on the water resource, and in the design and environmental assessment of new developments.

The absence of market mechanisms to arbitrate and allocate water among competing uses complicates this problem of balancing supply with demand. It has been estimated that, based upon willingness to pay, the most valuable uses of water are for recreation, power generation, and municipal use. However, water management on the prairies has focused traditionally on agricultural use. With increasing urbanization and affluence, water for recreation and in-stream use is becoming more important to the public and the prairie economy, and this trend will likely continue.

In the prairie region of North America, water resources are shared by a number of jurisdictions — three provinces and three states. Water flows from one jurisdiction to another, and the way water is used and managed in one province or state affects the way in which it can be used and managed in another.

TABLE 17.5

Water uses affected by existing water quality

	Water uses affected by existing water quality					
River basin	**Recreation**	**Raw drinking supply**	**Fish**	**Irrigation**	**Livestock watering**	**Cooling water**
Assiniboine	■	■	■	●	●	
Battle	●	—	■		●	●
Bow	■	—	●			
North Saskatchewan	■	—	■			
Oldman	●	●	●	●		
Missouri	●	●	●	■		
Qu'Appelle	■	■	■	■	●	●
Red Deer (Alberta)	●	●	●			
Red	■	■	■		●	●
Saskatchewan	■	●	■		●	
Souris	■	■	■	■	—	●
South Saskatchewan	●	■	—	●	●	

Legend

	Qualitative assessment	
Factor is of:	**Local**	**Basin-wide**
Known major concern	■	■
Known minor concern	●	—
Potential major concern	■	■
Potential minor concern	●	—
No concern		

Example

■ : Water quality and its effects on fish are known to be a major basin-wide concern in the Assiniboine River basin.

Source: Environment Canada, Inland Waters Directorate, Water Quality Branch, Western and Northern Region, Regina.

In order that all jurisdictions receive an equitable share of the resource, cooperative arrangements have been developed to define rights and responsibilities with respect to the quantity and quality of water that crosses political boundaries. For example, the International Joint Commission and the Prairie Provinces Water Board are two institutions that have been established under agreements between Canada and the United States and between Canada and the provinces, respectively. These institutions assist in monitoring and resolving issues related to the sharing of water resources of rivers crossing international and provincial boundaries in the grasslands.

Improving water quality

Ultimately, the acceptability of water quality is judged on the basis of the sustained use of water by all forms of life, including humans. On the basis of regional water quality monitoring, many water users have concerns about the existing quality of water across the grasslands region (Table 17.5). Most of these concerns relate to eutrophication, salinity, metals, and pesticides (Table 17.6) and for the most part are due to poor natural water quality. Human use has accelerated eutrophication, brought about deterioration in

Land and wildlife conservation

In recent years, an increasing awareness of the social, economic, and intrinsic values of native prairie ecosystems has evolved. Consequently, numerous conservation, mitigative, and protective programs have been initiated or are being considered in Canada's prairie grasslands region.

In order to conserve and protect species and ecosystems, a network of protected areas has been established across Canada (see Chapter 7). Protected areas fulfill a variety of functions, including (1) preservation of habitat, wildlife, and integral ecosystems; (2) public education; (3) tourism; and (4) recreation. In the Canadian prairies, the protection of remaining habitat and ecosystems is vitally important (World Wildlife Fund Canada 1988).

A major concern is the conservation of prairie grasslands, the subject of the Prairie Conservation Action Plan. At present, less than 5% of grasslands are protected, including Grasslands National Park, which is still at the pre-establishment (land acquisition) stage. This park, in mixed-grass prairie in Saskatchewan, will eventually consist of two separate blocks, totalling about 900 km^2. The area contains many prairie species, is the last area where the black-tailed prairie dog is still found in Canada, and would be one of the few suitable habitats for the reintroduction of the black-footed ferret. The largest areas of relatively undisturbed prairie habitat, however, are located on three military bases: Suffield (mixed-grass) and Wainwright (aspen parkland), in Alberta; and Shilo (aspen parkland) in Manitoba (World Wildlife Fund Canada 1988) (see Chapter 7).

An early signal of public concern for the value of the prairie ecozone came with its identification as an area of international significance for conservation in the World Conservation Strategy of 1980 (World Wildlife Fund Canada 1988). Other significant events were the publication of the report "Soil at risk" on soil conservation (Standing Committee on Agriculture, Fisheries and Forestry 1984) and three major new initiatives for prairie conservation: the signing of the Canada – United States agreement respecting the North American Waterfowl Management Plan (United States Department of the Interior/Environment Canada 1986), the release by the World Wildlife Fund of the Prairie Conservation Action Plan (World Wildlife Fund Canada 1988) and its subsequent endorsement by the governments of the three Prairie provinces, and the national soil and water accords concluded between the federal and provincial governments in 1989.

These programs differ in emphasis and agencies involved, but all recognize the link between environmental quality, habitat protection, soil conservation, and sustainable agriculture. The relationship between these issues and agricultural economics and policies is also beginning to be recognized (Girt 1990). Several programs, particularly the Prairie Habitat Joint Venture (the prairie component of the North American Waterfowl Management Plan) and the National Soil Conservation Program, emphasize education, demonstrations, and technology transfer for the farming community. These latter two and several provincial programs provide considerable financial compensation for conservation practices for limited periods of time. It is expected, and in fact is key to the success of such programs, that after the end of financial support, conservation practices will have proven economically and socially superior and will spread by example.

The North American Waterfowl Management Plan focuses on conservation of waterfowl habitat and has a considerable involvement of hunting groups, whereas the primary goal of the Prairie Conservation Action Plan is the preservation of areas of native grasslands, parklands, and riverine habitats. There are also several provincial programs with similar aims. The National Soil Conservation Program promotes practices that conserve soil and sustain long-term agricultural productivity. This three-year program, instituted in 1988, encourages the conversion of marginal agricultural lands to permanent cover and the creation of shelterbelts. Further information on programs for soil conservation and habitat is found in Chapter 26.

Urban landscape has often been forgotten as potential habitat; in fact, it contains significant areas where plants and even wildlife find protection. The federal–provincial Flood Damage Reduction Program in the three Prairie provinces has promoted keeping areas undeveloped near rivers that are at high risk of flooding and preserving them for their ecological value rather than exposing human habitation to flood damage. Urban centres have also taken action to set aside valleys and other urban landscapes for habitat preservation. Over 70 years ago, the City of Edmonton set aside its Whitemud River valley (a parkland ravine) for protection, and one of the last tall-grass prairie sites is preserved within the City of Winnipeg (St. James Living Prairie Museum) (Metcalfe 1985; World Wildlife Fund Canada 1988). Another prairie grass site is in Calgary (Nose Hill, a fescue prairie site), and the establishment of grassland sites within other urban centres (e.g., Saskatoon and Wainwright) is under discussion (S. Rowe, University of Saskatchewan, personal communication; G. Holroyd, Environment Canada, personal communication; H. Trefry, Environment Canada, personal communication). The only successful introduction (or reintroduction) of Peregrine Falcons in the Prairie provinces has occurred in cities (McNicholl 1988). Such sites within urban centres are small sanctuaries for prairie ecosystems, including animals, and at the same time provide some of the best opportunities for educating and increasing the awareness of the general public.

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TABLE 17.5

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Battle	●	—	■		●	●
Bow	■	—	●			
North Saskatchewan	■	—	■			
Oldman	●	●	●	●		
Missouri	●	●	●	■		
Qu'Appelle	■	■	■	■	●	●
Red Deer (Alberta)	●	●	●			
Red	■	■	■		●	●
Saskatchewan	■	●	■		●	
Souris	■	■	■	■	—	●
South Saskatchewan	●	■	—	●	●	

Legend

	Qualitative assessment	
Factor is of:	**Local**	**Basin-wide**
Known major concern	■	■
Known minor concern	●	—
Potential major concern	■	■
Potential minor concern	●	—
No concern		

Example

■ : Water quality and its effects on fish are known to be a major basin-wide concern in the Assiniboine River basin.

Source: Environment Canada, Inland Waters Directorate, Water Quality Branch, Western and Northern Region, Regina.

In order that all jurisdictions receive an equitable share of the resource, cooperative arrangements have been developed to define rights and responsibilities with respect to the quantity and quality of water that crosses political boundaries. For example, the International Joint Commission and the Prairie Provinces Water Board are two institutions that have been established under agreements between Canada and the United States and between Canada and the provinces, respectively. These institutions assist in monitoring and resolving issues related to the sharing of water resources of rivers crossing international and provincial boundaries in the grasslands.

Improving water quality

Ultimately, the acceptability of water quality is judged on the basis of the sustained use of water by all forms of life, including humans. On the basis of regional water quality monitoring, many water users have concerns about the existing quality of water across the grasslands region (Table 17.5). Most of these concerns relate to eutrophication, salinity, metals, and pesticides (Table 17.6) and for the most part are due to poor natural water quality. Human use has accelerated eutrophication, brought about deterioration in

TABLE 17.3

Water quality concerns

	Water quality characteristics									
River basin	Nutrient enrichment	Weeds and algae	Taste/ odour/ smell	Dissolved salts	Sediment	Bacteria	Industrial toxics	Mercury in fish	Other metals	Pesticides
Assiniboine	■	■	■	●	●	●	●	■	●	—
Battle	■	■	■		●	●		●		—
Bow	■	■	■	●	●	■	■	●	●	—
North Saskatchewan	■	●	●		—	■	■	■	●	—
Oldman	—	—	●	●	●	■		●		—
Missouri				—			●	●	●	—
Qu'Appelle	■	■	■	■	■	■	●	■	●	—
Red Deer (Alberta)	●	●	●	●	■	●	●	●		—
Red	■	■	■	●	—	■	■	—	■	—
Saskatchewan	●	●	●	●	■	■	●	■	■	—
Souris	■	■	■	■	—	—	●	■	●	—
South Saskatchewan	■	■	■	■	■	■	■	■		—

Legend

	Qualitative assessment	
Factor is of:	Local	Basin-wide
Known major concern	■	■
Known minor concern	●	—
Potential major concern	■	■
Potential minor concern	●	—
No concern		

Example

■ : Taste,odour and smell of water supplies are known to be a major water quality concern throughout the Qu'Appelle River basin.

Source: Environment Canada, Inland Waters Directorate, Water Quality Branch, Western and Northern Region, Regina.

the bacteriological quality of some regional waters, and introduced toxins to the prairie ecosystems.

Water quality on the prairies is not getting significantly worse in most respects but is close to a minimal level at many locations, and current economic, social, and climatic trends may cause it to drop to an unacceptable level. To prevent deterioration of water quality, contaminant loadings need to be reduced and water quality management plans need to be developed and implemented.

What is being done on the grasslands to improve water quality? Municipalities across the prairies have upgraded their sewage treatment systems over time (Fig. 17.13). Between 1983 and 1989, the percentage of the population served by tertiary treatment in the 12 Census Metropolitan Areas in the grasslands increased from 8 to 32% (Environment Canada, Inland Waters Directorate, Municipal Water Use Data). Provincial policies and regulations now prohibit the discharge of raw sewage directly to the environment and require a minimum level of secondary treatment. Some major centres, such as Winnipeg, Manitoba, and Saskatoon, Prince Albert, and Yorkton, Saskatchewan, are upgrading their treatment systems to conform to these regulations.

Concern about water quality in the Red River and Assiniboine River, particularly near Winnipeg, has led the federal government to propose, under Canada's Green Plan, a joint study with the provinces of Manitoba and Saskatchewan on water use, sources and effects of pollutants, soil conservation, and wildlife habitat in the Red River and Assiniboine River basins (Government of Canada 1990). It is hoped that a better understanding of the cumulative effects on water quality of the many industrial, agricultural, and municipal activities that take place in these river basins will help determine priority areas for preventative and remedial action.

Significant improvements in irrigation practices coupled with capturing irrigation return flows for reuse have helped to protect the quality of the main stem of river systems. Reservoirs have provided opportunities for augmenting river discharge during periods of low flow to replenish low dissolved oxygen and to improve water quality. The levels of oxygen dissolved in the North Saskatchewan River as it flows through Edmonton have significantly increased in recent years because of regulation of the upstream flow and improved wastewater treatment. Recent court actions have indicated an interest on the part of the public in environmental evaluations of projects such as the Rafferty–Alameda dams in southeastern Saskatchewan and the Oldman Dam in southern Alberta.

The grasslands region has so far escaped the devastating effects of industrial toxic wastes, although there are areas of mainly local concern. In Alberta, for example, there are three high-priority abandoned sites that qualify under the National Contaminated Sites Remediation Program for remedial action with joint funding by the provincial and federal governments. These sites are the old Canada Creosote plant site at Calgary, the Peerless Wood Preserving operation at

Cayley, and the former Purity 99 refinery site at Hartell. Potential candidate sites in Manitoba and Saskatchewan are currently being considered for funding under this program.

The future

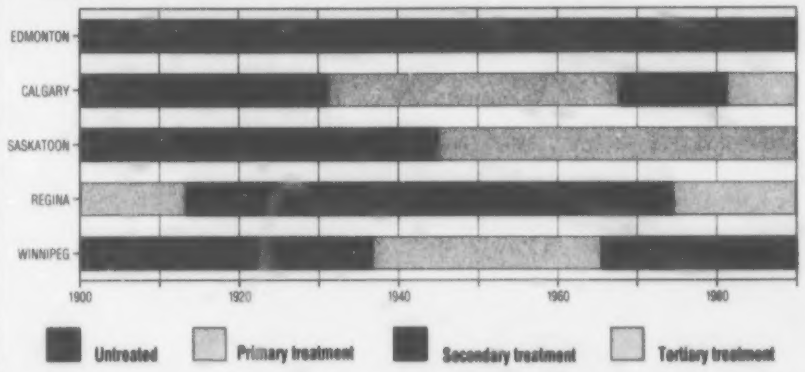
The traditional view of water and other environmental resources as an input to economic activity in the short term will be replaced by a growing public awareness of the true value of these resources to sustain the economy and the environment over the long term. Water management practices, in particular, will likely rely more and more on demand management, conservation, and water quality management as a means to allocate and protect the quality of the scarce resource for the uses that society judges most important.

Water resources, given their high economic and social value, should no longer be considered as a disposal ground for wastes; nor should the unintended negative consequences of how we manage land be allowed to continue if they adversely affect the water resource. Water quality management in the future thus must emphasize the control of pollution at the source. Land-use management approaches, including soil conservation, should also be developed and evaluated with respect to the enhancement of the quality and conservation of water.

The value of land is also taking on a much broader context. Marginal lands for agriculture are not wastelands but should be valued as habitat and for their function within the hydrologic cycle. Land mined of its soil productivity by intensive farming or of its minerals for short-term profit will only be of value to society over the long term if protection, restoration, and reclamation are considered as a cost of doing business. Efforts must be shifted to long-term management and reclamation policies and practices in order to sustain soil productivity. Environmental stewardship is the key to ensuring the long-term viability of the grasslands economy.

FIGURE 17.12

History of sewage treatment in Prairie cities, 1900–90



Source: Environment Canada, Inland Waters Directorate, Water Quality Branch, Western and Northern Region.

CONCLUSIONS

The exploitation of the area's soils, oil and gas, coal, and minerals, coupled with favourable market conditions, have allowed settlement and supported economic activities in the prairie grasslands region. This makes the protection and enhancement of the grasslands' environmental resource base important for continued prosperity and quality of life in an increasingly competitive world economy.

Native prairie ecosystems are some of the most endangered in Canada. Between 40 and 71% of the original wetland habitat has been converted to other uses, primarily agriculture, and almost all of the native prairie has been eliminated, along with some animal communities unique to the grasslands. Wastewater discharges from the large cities of the grasslands have adversely affected water quality downstream and such water uses as recreation, fisheries, and municipal uses that depend upon high-quality waters. Economic development is at the limit of available water supplies in some basins in the prairies, and further development will have to consider improvements in efficiencies of existing and future uses. Especially during drought years, there are growing concerns in southern Alberta and Saskatchewan that increasing consumptive uses will prevent in-stream requirements for aquatic ecosystems, especially those that support fisheries, from being met.

Canada's grasslands are unique from a climatic, topographic, hydrologic, environmental, and socioeconomic perspective. The challenge for those who set environmental and resource management policy will be to preserve the region's unique heritage of soils, water, vegetation, and wildlife to ensure the long-term viability of the grasslands economy.

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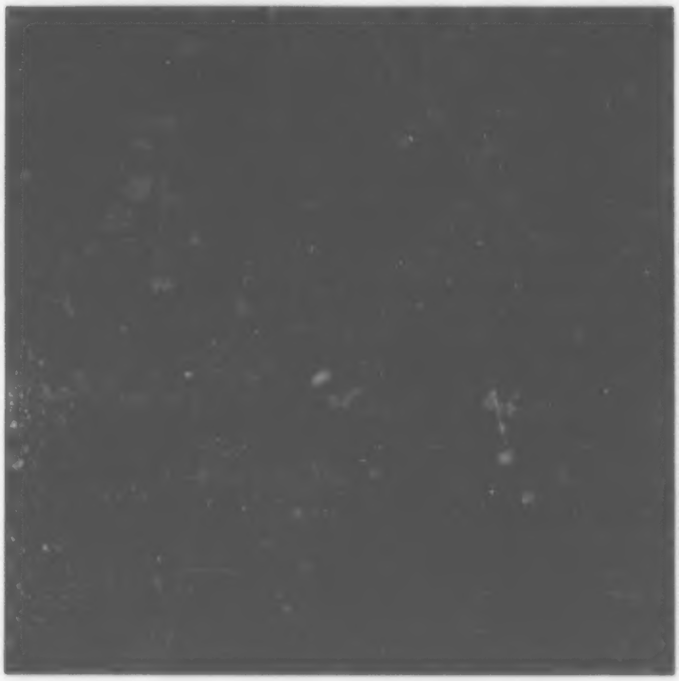

COURTESY OF CANADA CENTRE FOR REMOTE SENSING, ENERGY, MINES AND RESOURCES CANADA, OTTAWA

HIGHLIGHTS

The Great Lakes have played a key role in the rise of North American industrial society. However, they have paid a high price for their contribution, having suffered profound environmental degradation. Municipal sewage, industrial and agricultural chemicals, and overfishing have stressed the ecosystem to the limits of its endurance, and the integrity of this magnificent system is now threatened.

■

Development has swallowed up two-thirds of the basin's wetlands — the most productive component of the Great Lakes basin ecosystem. Remaining wetlands play a critical role as a feeding ground for fish and migratory waterfowl, and further losses ultimately could threaten the survival of several species of endangered plants and animals.

■

All of the lakes are threatened by an accumulating load of toxic contaminants, the by-products of the chemical revolution that has taken place over the last four decades. These contaminants are stored in the tissues of plants and animals, then biomagnified through the food chain to dangerous levels. One such toxic chemical, DDT, has been conclusively linked to reproductive failure in fish-eating birds. Some substances affect normal tissue development. Tumours and cancers have been observed in adult fish. Young birds appear most susceptible, displaying a disturbingly high rate of birth deformities in areas where toxic contaminants occur in high concentrations.

■

Humans, too, may be threatened by long-term, low-level exposure to toxic contaminants. A study of Michigan women who regularly consumed Great Lakes fish during their pregnancies demonstrated that their newborns had neurobehavioural and physical defects, and, as four year olds, suffered learning deficits.

■

The 1978 Canada–U.S. Great Lakes Water Quality Agreement undertook "to restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes basin ecosystem."

■

Remedial Action Plans are being developed to clean up 43 areas around the lakes where there are long-standing problems of water pollution. Remedial Action Plans involve concerted action by governments, environmental groups, industries, and others.

■

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> “There are two great ironies about the Great Lakes: first, that the people who have become so dependent upon them have misused them the most; and second, that despite our abuse of them the lakes remain as wondrous as they must have seemed to Melville and indeed to Étienne Brûlé, the first European to see them, when he stood on the shores of Georgian Bay in 1610.”
>
> — John Rousmaniere (1979)

INTRODUCTION

As well as anywhere in the world, the Great Lakes basin exemplifies the modern tendency to push the environment to the brink. The poignant environmental history of the Great Lakes has been marked by a number of crises. The first arose early in this century, when raw sewage contaminated the drinking water, leading to tragic typhoid and cholera epidemics. Between the 1930s and the 1960s, native fish populations were decimated by overfishing, introduction of exotic fish species, and deterioration of water quality. By the 1960s, algal blooms fed by domestic phosphate detergents, human waste, and inorganic agricultural fertilizers conspired to "kill" Lake Erie. At the same time, oil, organic sludge, and debris from industrial and municipal sources polluted many nearshore areas to such an extent that, in one notorious instance, the Cuyahoga River in Ohio actually caught fire. More recently, it has become apparent that toxic chemicals in the aquatic environment are causing reproductive effects and deformities in wildlife and therefore must be considered threatening to human health.

These crises were brought on by population growth and changing lifestyles. As highway and source of raw materials, the lake system has played a key role in the rise of agricultural and industrial society in the New World, and, by the late 1980s, the basin held nearly 35.1 million residents (Colborn *et al.* 1990). However, the ecosystem has paid a high price for its contribution, suffering unrelenting environmental degradation.

In the past, we have viewed pollution as an acceptable price for progress. However, society is beginning to realize that it can no longer afford to divorce the pursuit of socioeconomic success from an equal concern for environmental well-being. By so doing, we had brought ourselves close to ecological catastrophe. Current trends, however, give cause for optimism. Policy-makers now recognize that nonliving components of the ecosystem — land, air, surface water, wetlands, and groundwater — provide vital support for the biological system, including people.

THE GREAT LAKES BASIN ECOSYSTEM

Moiseev (1987) singled out the Great Lakes system as an important part of the global heritage and one of the absolute values our planet possesses. An examination of its attributes substantiates these claims.

The Great Lakes constitute the largest freshwater lake system in the world. It is the source of the St. Lawrence River, through which nearly all Great Lakes water drains on its journey to the Atlantic Ocean. In addition to the five Great Lakes (Superior, Michigan, Huron, Erie, and Ontario) and their connecting water bodies (St. Marys, St. Clair, Detroit, and Niagara rivers, plus Lake St. Clair), the surface water system includes 750 000 km of tributary streams and rivers and over 80 000 small upland lakes, which, combined, exceed the area of Lake Erie. Almost 20% of the world's supply of fresh water in lakes and rivers is held in this massive system, which drains an area of 765 990 km^2. Figure 18.1 shows the Great Lakes with bordering Ontario and the eight Great Lakes states, and Figure 18.2 provides a summary of physical characteristics of the Great Lakes.

Historically, the surface water has provided energy, fish, transportation, drinking water, and recreational opportunities. Although surface water is the dominant feature, it is only one component of a multifaceted Great Lakes basin ecosystem. Groundwater, wetlands, air, biota, and land all combine with surface water to produce the richness and diversity that characterizes the Great Lakes basin.

Surface water

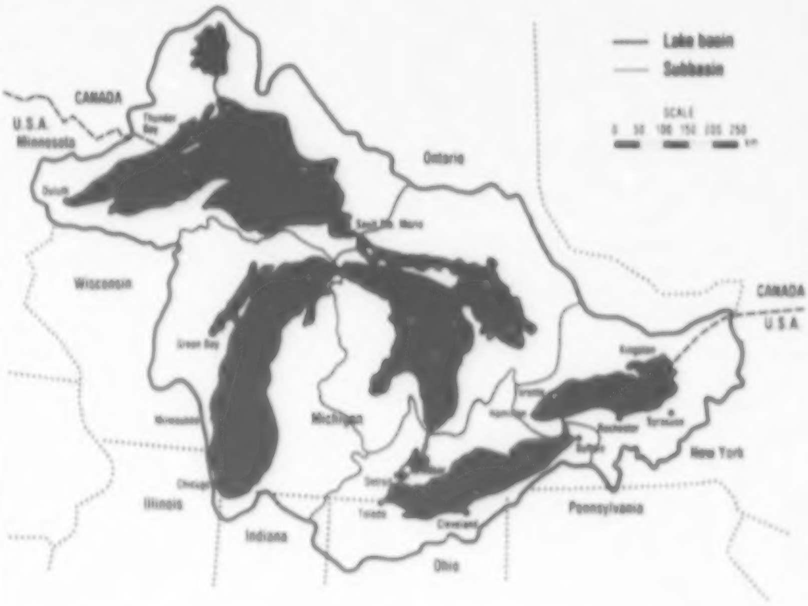
Surface water is the natural unifying component of the Great Lakes basin ecosystem. Surface water drainage defines the geographical limits of the basin, and vegetation, wildlife, and the human population are intimately connected to quantity and quality of surface waters.

Water quality in the lakes has become degraded in part because of the following three characteristics of the surface water system:

1. No part of the drainage basin is more than 320 km from one of the Great Lakes, and, in several locations on the U.S. side, the area draining to the basin is only a few square kilometres. Because tributaries are generally short, contaminants from upland sources reach the lakes rapidly.
2. The large surface area of the Great Lakes makes them vulnerable to direct atmospheric pollution — now recognized as the dominant source of contaminants in the upper lakes.
3. Flushing time of the lakes is very long, leading to the accumulation of contaminants in the system. Less than 1% of the volume of the Great Lakes themselves exits the system each year through the St. Lawrence River. Lake Superior, which holds more than half of the water by volume in the Great Lakes system, has a retention time of 191 years, and Lake Michigan, 99 years. While in the system, contaminants tend to stick or bind to particles and sink to the bottom, where they become part of the lake sediments, or they are ingested by organisms and incorporated into the food web. In short, contaminants can be retained for many years, and can pass back and forth between water and other components of the ecosystem.

FIGURE 18.1

The Great Lakes basin


Lake basin
Subbasin
SCALE
0 50 100 150 200 250 km
CANADA
U.S.A.
Minnesota
Thunder Bay
Duluth
Ontario
Sault Ste. Marie
Wisconsin
Green Bay
Milwaukee
Michigan
Chicago
Illinois
Indiana
Detroit
Toledo
Cleveland
Ohio
Toronto
Hamilton
Kingston
Rochester
Syracuse
Buffalo
New York
Pennsylvania
CANADA
U.S.A.

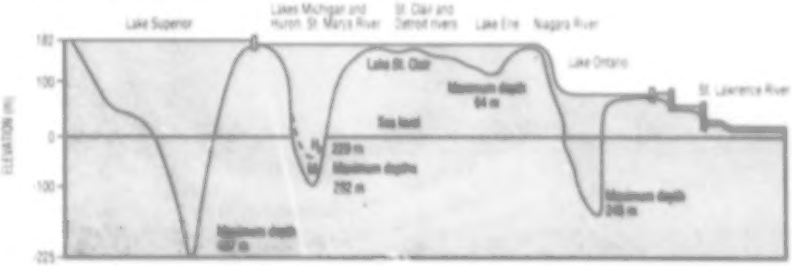
Source: Colborn *et al.* (1990)

FIGURE 18.2

Physical characteristics of the Great Lakes

Lake	Area of lake (km²)	Average depth (m)	Volume (km³)	Retention time (years)
Superior	82 100	147	12 100	191
Michigan	57 800	85	4 920	99
Huron	59 600	59	3 540	22
Erie	25 700	19	484	2.6
Ontario	18 960	86	1 640	6

Depth profile of the Great Lakes

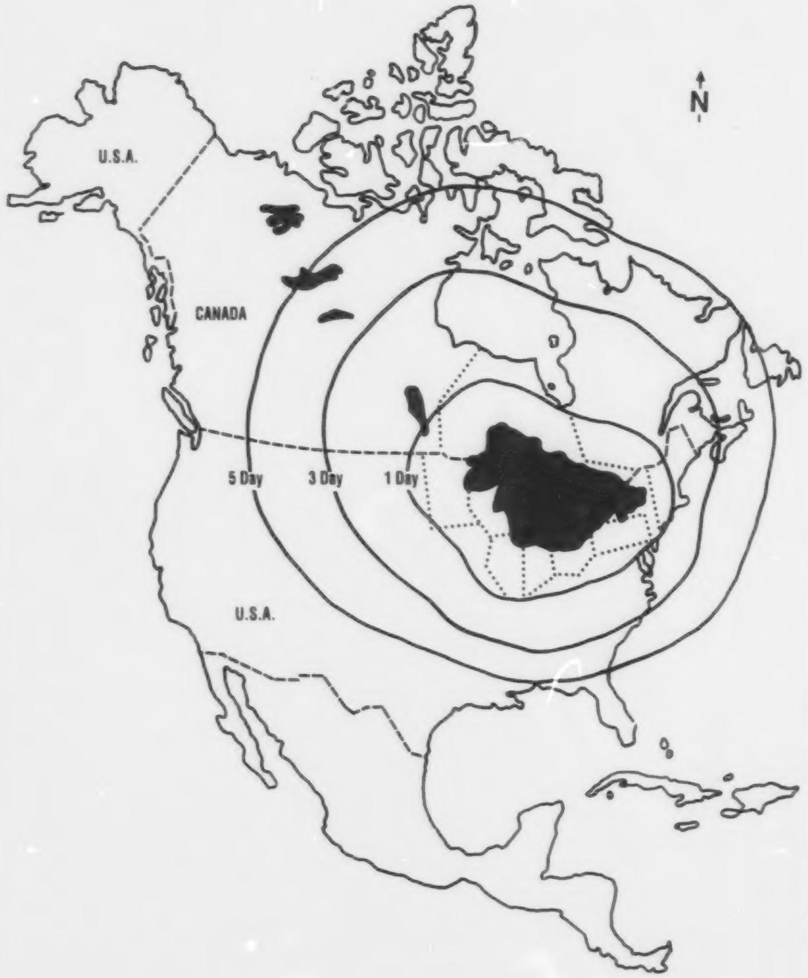


Source: Colborn *et al.* (1990)

FIGURE 18.3

One-, three-, and five-day atmospheric regions of influence for the Great Lakes basin

Lines indicate the median location of airborne contaminants originating one, three, and five days before their arrival in the Great Lakes hydrological basin. Regions more remote than five days can also contribute significantly to pollutant loadings to the Great Lakes basin.



Source: Colborn *et al.* (1990).

Groundwater

In 1978, the President of the United States declared that the Love Canal hazardous waste site, near Niagara Falls, was a disaster area. Since that time, groundwater has begun to receive public recognition as a key element in the ecosystem.

As well as being a direct source of water for human consumption, groundwater feeds wetlands, streams, rivers, and lakes and, inevitably, transports contaminants to surface water from a broad range of sources. In the Great Lakes system, the direct groundwater contribution to the Great Lakes proper is likely negligible; however, its contribution to tributary flow may be over 50% in some regions (Hodge 1989). In the southern part of the Great Lakes basin, cold-water fish, such as trout, are able to live in streams throughout the warm summer months due largely to cold-water springs fed by groundwater (Meisner *et al.* 1988).

Wherever contaminants are not contained by either natural or human-made barriers, they can move into groundwater and lead to significant degradation of the environment. A particularly serious problem exists along the Niagara River between lakes Erie and Ontario where groundwater-borne chemicals, with origins in dozens of hazardous waste sites and operating plants, are the largest single source of contaminants entering the Niagara River (Hodge 1989). Implications exist not only for the water quality of the Niagara, but also for the ecosystems of Lake Ontario and the St. Lawrence River beyond.

Within the Great Lakes basin, roughly 7.5 million of the 35.1 million residents (21%) depend on groundwater for their drinking water (Colborn *et al.* 1990). The Waterloo region in southern Ontario is the largest region in Canada to depend solely on groundwater for its water supply (J.A. Cherry, Waterloo Centre for Groundwater Research, personal communication). Groundwater withdrawals can cause significant problems if they are more than the natural system can replenish — a practice called "mining" of the groundwater. Although the most extreme examples of this problem are in the Chicago–Milwaukee area (Young *et al.* 1986), overpumping of groundwater appears to be an emerging problem in some of the growing suburbs in southern Ontario (Pupp *et al.*, in preparation).

Whereas movement in surface water can be measured in hours and days, groundwater movement sometimes takes centuries. Any action that negatively affects its quantity or quality may have a profound influence on the quality of life of future generations.

Air

The Great Lakes basin ecosystem is open to many external influences. As a dramatic demonstration of this, in the late 1970s, the insecticide toxaphene, which was largely used in the southern United States to control insects on cotton crops, was found in dangerously high levels in Great Lakes fish.

Pollutants released into the atmosphere within regions of influence of the Great Lakes may travel hundreds or even thousands of kilometres in air masses before finally falling to the lakes several days later. Figure 18.3 shows one-, three-, and five-day atmospheric regions of influence for the Great Lakes basin. The lines indicate the median locations of the sources of airborne contaminants originating one, three, or five days before their arrival in the Great Lakes. For example, key ingredients of acidic deposition, such as nitric acid and sulphur dioxide, remain airborne for less than one day.

The large water surfaces of the five Great Lakes and the other lakes in the basin make them particularly vulnerable to atmospheric pollution. Table 18.1 lists PCB inputs to the Great Lakes that can be attributed to atmospheric deposition.

TABLE 18.1

PCB inputs to the Great Lakes and the percentage attributed to atmospheric deposition

Lake	Total inputs (kg/year)	Percentage attributed to atmospheric deposition	
		Direct[a]	Indirect[b]
Superior	606	90	< 1
Michigan	685	58	< 1
Huron	636	63	15
Erie	2 520	7	6
Ontario	2 540	6	1

[a] Direct deposition to the lake surface.

[b] Deposited in an upstream water body that subsequently flows into one of the lakes.

Note: Due to Superior's large surface area, 90% of the PCBs found in the lake are estimated to arrive through atmospheric deposition. The absolute amounts entering the upper Great Lakes are significantly smaller than those entering lakes Erie and Ontario. These differences reflect the higher concentration of human activity adjacent to the lower lakes and the larger proportion of direct contribution of contaminants through effluent discharge to surface water. Even in the lower lakes, however, the annual input from the atmosphere is significant. These are smaller bodies, and so the effect of airborne contamination on their water quality is important.

Source: Strachan and Eisenreich (1988).

Land

The land around the Great Lakes exhibits great diversity, encompassing two ecozones, the Boreal Shield and the Mixed Wood Plains (see Fig. 5.1 and Table 5.1). In the north, the ancient granitic rocks of the Canadian Shield underlie much of the Canadian portion of the basin, and in the south, younger sedimentary rocks are found. During the last million years, continental glaciers, 2 km thick, advanced and retreated four times. In their passage, the glaciers ground the underlying rock and pushed it south, depositing silts, sands, gravels, and boulders in layers sometimes over 100 m thick. Retreating for the last time 12 000 years ago, the glaciers sculpted the current landforms, including the giant bowls that filled with water to become the Great Lakes.

The Canadian Shield is marked by vast forests and thousands of small lakes. The ancient shield bedrock and shallow soils are susceptible to the effects of acidic deposition. In contrast, to the south of the Canadian Shield, the sedimentary rocks commonly include carbonate rocks (limestone, dolomite) that counteract or "buffer" some effects of acidic deposition (see Chapter 24).

The gentle topography and rich, acid-tolerant soils in the southern part of the basin provide some of the richest farmland in the world. Agriculture not only is important to the regional economy, but also has contributed significantly to environmental degradation of the lakes. Erosion has damaged fish habitat, inorganic fertilizers have led to algal growth and oxygen depletion in the lakes, and chemicals used in modern row crop agriculture have added to the load of toxic contaminants in the water.

Biota

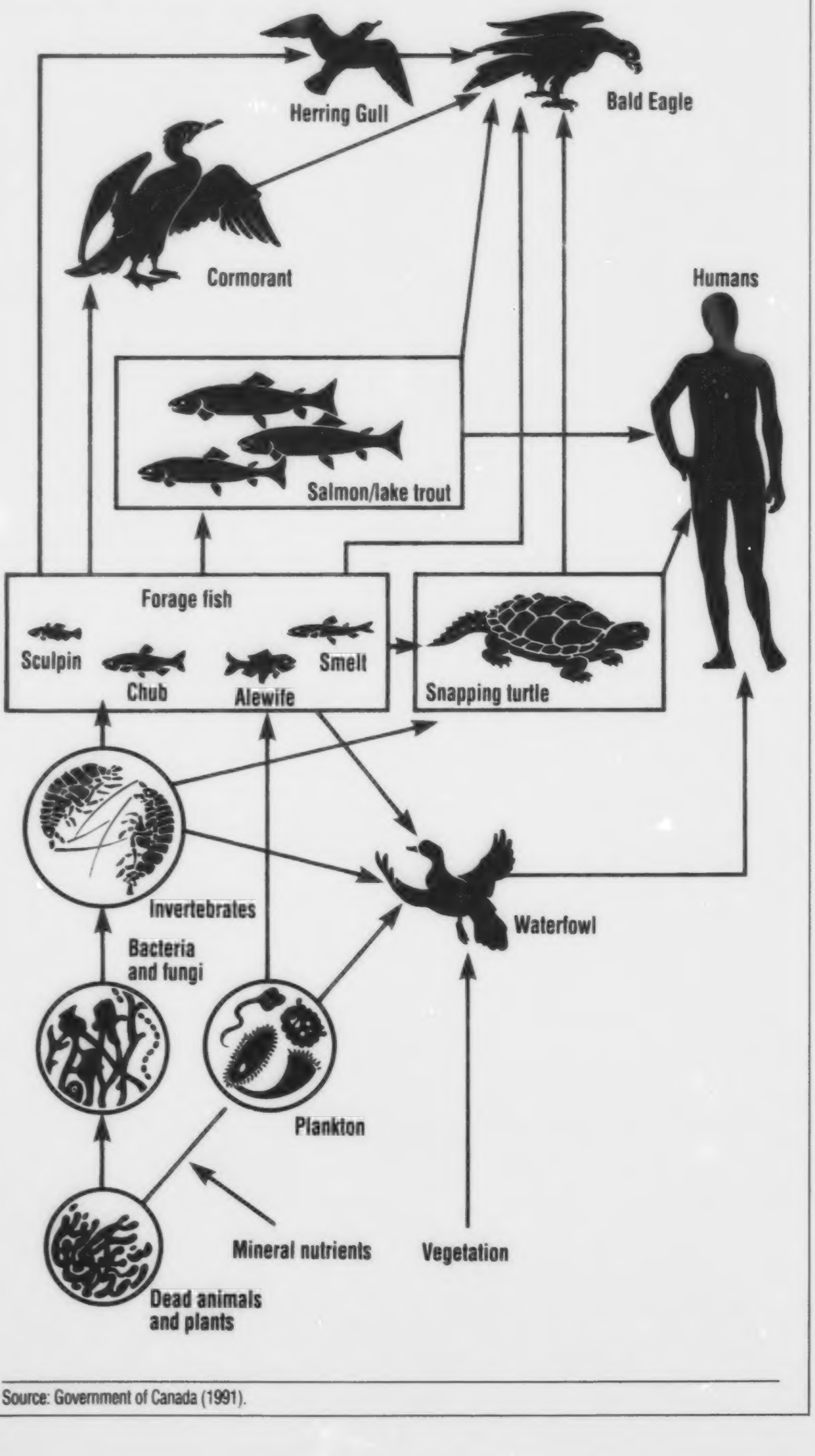
Plants and animals

The Great Lakes basin supports tens of thousands of species of aquatic and terrestrial plants and animals and, despite recent losses of species and changes in species composition, is still a productive and diverse ecosystem.

Most of the Canadian portion of the basin is covered by mixed evergreen and deciduous forests supporting abundant wildlife. Within the lakes themselves, phytoplankton (tiny plants), capable of converting solar energy into organic compounds, form the basis of the food chain.

FIGURE 18.4

Simplified Great Lakes food web


Herring Gull
Bald Eagle
Cormorant
Humans
Salmon/lake trout
Forage fish
Sculpin
Chub
Alewife
Smelt
Snapping turtle
Invertebrates
Waterfowl
Bacteria
and fungi
Plankton
Mineral nutrients
Vegetation
Dead animals
and plants

Source: Government of Canada (1991).

Both aquatic and terrestrial ecosystems are rich, diverse, and interconnected through vast food webs that transfer energy, nutrients, and toxic contaminants from species to species. Figure 18.4 depicts a simplified Great Lakes food web, showing relationships between some of the better-known species, including lake trout, salmon, Herring Gulls, Bald Eagles, and humans.

Just as the chemistry of their surroundings is critical to all living species, so too are the availability of appropriate physical habitat and the presence of compatible species. The loss of, and physical changes to, habitats, particularly wetlands, as well as disruption of species distribution through overharvesting and the introduction of non-native species, remain major concerns in the Great Lakes system. Climatic change may prove to be even more important, as changes to temperature and moisture regimes will likely alter many types of habitat.

The human element

Early European explorers recorded how portions of the Great Lakes were so temperate, fertile, and beautiful that they were called the earthly paradise of North America (Allan 1985). European settlers were quick to transform this paradise into something quite different.

A single, grim statistic illustrates just how quickly. Before 1634, Champlain estimated that the native population of what is now southern Ontario was about 30 000, a figure supported by modern archaeological records. By 1639, epidemics of European diseases (probably measles, influenza, and smallpox) had devastated the region's indigenous people, leaving only 12 000 survivors (Heidenreich 1987; Wright 1987).

In the excitement of creating a "New World," and with the sense of plenty that was the order of the day, Great Lakes pioneer society began the process of environmental degradation. The recent shift in the region's economic base, from subsistence resource extraction to an internationally connected industrial and service complex, has accelerated the pace and degree of environmental change. Great Lakes settlers drained over two-thirds of the basin's original wetlands, areas that once teemed with life, to furnish farmland and urban areas or simply to eliminate "swamps"; they dammed thousands of rivers and streams for water supplies, irrigation, mills, and energy production; they harvested vast forests for lumber and turned the land into fields; they fished species of once-common fish to extinction and destroyed the habitat of other species; they carved transportation corridors and erected harbours, towns, and cities, thus eliminating vast areas of wildlife habitat. As this dismantling of the ecosystem proceeded, one of the world's most productive areas of industrial and agricultural activity emerged in its place, with a combined annual gross domestic product exceeding $1 trillion (Davidson and Hodge 1989).

A key development in the transformation of the lakes from their pristine state has been the extraordinary increase in the use of chemicals over the last 40 years. This trend has touched all facets of daily life and left its mark on the entire ecosystem. New pollutants have been discharged, in massive quantities, into the air, land, and water.

All of these changes were accompanied by a population growth from 100 000 indigenous people scattered through the basin in the early 1600s (Environment Canada *et al.* 1988) to the 1986 population of 35.1 million, of which 7.8 million were Canadian (31% of the national population) and 27.3 million were American (11.5%). This population can be expected to increase as development continues in the basin. In 1986, 84% of Canadian residents of the Great Lakes basin lived in urban areas, a characteristic paralleled on the U.S. side. These patterns are reflected in the different population densities found around each Great Lake (Table 18.2).

Current land-use patterns are shown in Figure 18.5. All of these aspects of human activity — forestry in the north, agriculture in the south, and the concentration of industry and population around the lakes, with their broad related support structures, including energy production and transportation services — continue to force environmental change.

AN ECOSYSTEM UNDER STRESS

Ecosystems experience a wide range of naturally occurring and human-induced stresses, which, for the sake of convenience, can be organized under five

TABLE 18.2

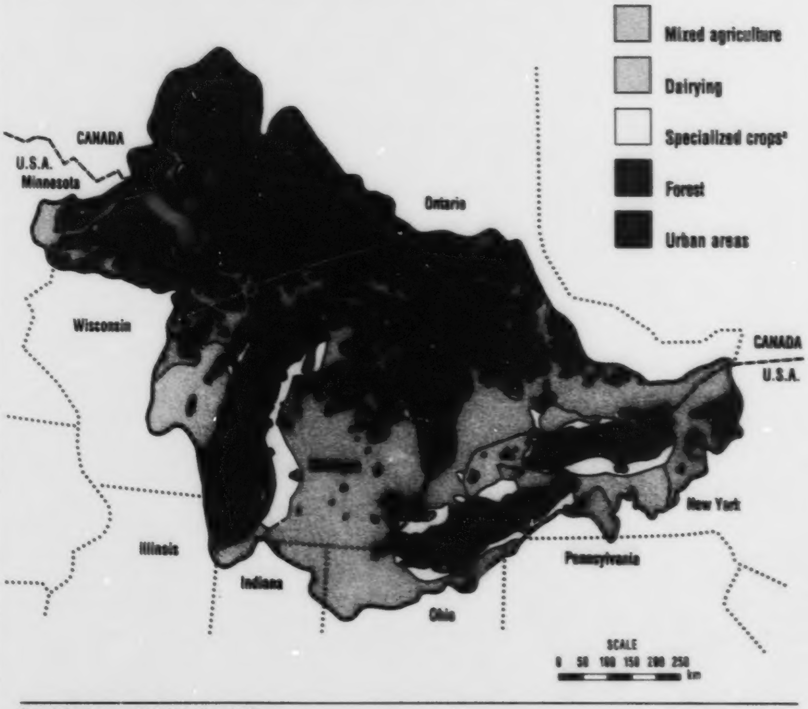
Drainage area and population density for each of the Great Lakes (total Canada and U.S.)

Lake	Drainage area (km²)	Population (1986)	Population density (residents/km²)
Superior	127 700	663 465	5.2
Michigan	118 000	12 051 200	102.1
Huron	134 100	2 461 115	18.4
Erie	78 000	12 532 770	160.7
Ontario	64 030	7 375 280	115.3
Total	**521 830**	**35 083 830**	**67.2**

Source: Colborn *et al.* (1990).

FIGURE 18.5

Land use in the Great Lakes basin



[a] Specialized crops include fruit and tobacco.

Source: Colborn *et al.* (1990).

TABLE 18.3

Naturally occurring and human-induced stresses experienced by the ecosystem

Stress	Example
Natural processes	• weather-related (wind, storms, rain, flooding, drought, freeze–thaw cycles) • natural fires in forests, grasslands, and marsh areas • disease, parasites, and other causes leading to natural shifts in vegetation and wildlife populations
Addition or loading of substances, heat, radionuclides, etc.	• discharge of phosphorus, nitrogen, and other nutrients that serve to fertilize plants, including lake phytoplankton • discharge to land, air, or water of a vast range of chemicals, including pesticides; industrial, municipal, and transportation by-products and wastes; and carbon dioxide and other greenhouse gases • erosion and deposition of sediments • discharge of waste heat to air or water
Restructuring of the physical environment and land-use change	• damming, diking, dredging, filling, or other modification of waterways and lakes • shoreline protection (groins, seawalls, and modifications such as harbour construction) • trees and shrub clearance for agriculture, industry, or settlement development • wetland drainage, excavation, and development
Harvesting/extraction of renewable and nonrenewable resources	• water withdrawals (from surface or wells), diversions, and consumptive use • commercial forestry • fishing (subsistence, commercial, or recreational), hunting, trapping • extraction of minerals and building materials
Introduction of nonnative organisms	• intentional importation of plants or animals, including stocking lakes with exotic fish • unintentional introduction of new species, such as through canal construction, escape from aquariums, transport on boat or ship hulls, in ballast water, etc. • presence of pathogenic organisms in nonnative species, which then spread to native species

Source: Rapport and Friend (1979); Rapport (1983); Bird and Rapport (1986); Regier (1988); Colborn *et al.* (1990).

distinct categories (Table 18.3). These stresses often occur simultaneously, making it difficult for those assessing the state of the environment to isolate specific causes and effects. Moreover, reliable, relevant quantitative data are often lacking, and therefore anecdotal evidence of environmental change must be relied upon. On the other hand, in a complex system such as the Great Lakes, assessment should depend not only upon "hard" numbers, but also upon best judgement.

To help in this task, researchers have determined that certain biological characteristics indicate when an ecosystem is undergoing stress (Table 18.4). The Great Lakes basin exhibits most of these danger signals, including altered biological productivity, reduction in species diversity, changes in species composition, and shifts toward more opportunistic species. This section examines in more detail the stresses imposed upon the ecosystem of the Great Lakes basin and its response to them.

Loss of habitat

"There is nothing but continuous marshes," marvelled Jacques Sabrevois in 1718, as he stood at the mouth of the Maumee River in the former Black Swamp that once encompassed most of the west end of Lake Erie. "In these there is, at all seasons, game without end, especially in the autumn and in spring: so that one cannot sleep on account of the noise made by cries of swan, bustards, geese, ducks, cranes, and other birds."

Since Sabrevois's time, two-thirds of all wetlands, the most biologically productive component of the Great Lakes basin, have been destroyed (Colborn *et al.* 1990). Table 18.5 summarizes estimates of wetland losses in various parts of the basin.

In southwestern Ontario, wetland losses are continuing. Between 1967 and 1982, Kent County lost 26% of its original wetland area, and Essex, Lambton, and Middlesex counties between 10 and 20% (Snell 1987). Between 1965 and 1984, 30% of the Lake St. Clair shoreline wetlands were lost (McCullough 1985). On the Canadian side of Lake Ontario, 43% of wetlands have been destroyed, with losses as high as 75% in urban areas (Whillans 1982).

Remaining wetlands play a critical role in supporting fish (Stephenson 1990) and other wildlife. Some species depend totally on wetland habitat; others use wetlands during critical stages in their life cycles. Coastal wetlands on the lower lakes are especially important for migratory waterfowl, providing birds from both Mississippi Flyway and Atlantic Flyway populations with the most extensive and high quality feeding habitat south of James Bay (McCullough 1985). They also furnish food and nesting habitat for wildlife populations native to the lower lakes. Loss of wetland habitat has been a

TABLE 18.4

Typical biological characteristics of an ecosystem under stress

1. Reduction in number of native species and in species diversity
2. Reversion to ecological communities that are unstable in the long term and to an earlier and usually subverted stage of succession that is not typical for the particular area
3. Shift towards more opportunistic species
4. Reductions in the average size of dominant biota
5. Unnatural rapid alteration in the quantity of either living or dead biomass
6. Impaired biological productivity
7. Changes in primary energy production and energy flow through the system
8. Higher susceptibility to disease (except in instances where the stress weakens the disease more than the host)
9. Changes in mineral macronutrient stocks

Source: Bird and Rapport (1986); Herricks and Schaeffer (1987).

TABLE 18.5

Wetland losses in the Great Lakes basin

Province or state	Wetland losses[a] in the Great Lakes basin
Ontario	90% in Essex, Kent, and Lambton counties (southwest Ontario); 68% in areas south of the Canadian Shield; 39% along the Lake St. Clair shoreline (1910–78); 35% along the Lake Erie and Lake Ontario shorelines
Illinois	90%
Indiana	86% in areas studied, and 71% in northern Indiana
Michigan	71%
Minnesota	76% (since 1953)
New York	no overall assessment found
Ohio	almost the entire 3 885-km² Black Swamp
Pennsylvania	no overall assessment found
Wisconsin	50%

[a] Ontario estimates are since 1800, unless otherwise noted; U.S. estimates are statewide and since presettlement, unless otherwise noted.

Source: McCullough (1985); Snell (1987); Weller (1988); Colborn *et al.* (1990).

major factor in listing 12 species of plants and animals under Ontario's *Endangered Species Act* — all of these species require wetland habitat during some part of their life cycles. Finally, wetlands also provide spawning or nursery habitat for many fish, both game and forage species. Therefore, any further wetland losses may pose a great threat to the future well-being of the remaining fishery.

Municipal waste, nutrient enrichment, and eutrophication

In 1882, 180 people of every 100 000 in Ontario died of typhoid, cholera, or similar diseases. The reason was simple: towns and cities of the day, without forethought, routinely placed drinking water intakes close to sewer outfalls; in Sarnia, for example, the two were only 45 m apart (Koci and Munchee 1984). Society reacted to the first major environmental crisis in the basin by extending water intakes farther into lakes or upstream in rivers and eventually chlorinating drinking water supplies that had become contaminated with sewage (Steedman 1986). In Toronto, chlorination started in 1910 and resulted in immediate dramatic reductions of typhoid fever, tuberculosis, and infant mortality. The epidemics disappeared and the bacterial problems appeared solved. In fact, they were not. In the late 1940s and early 1950s, studies initiated by the International Joint Commission found bacterial levels in some areas triple those observed in the early part of the century The earlier action of chlorination had served to mask rather than solve the problem. It took another crisis of a different kind to force a comprehensive cleanup of municipal sewage, which remains far from complete today.

In the 1960s, parts of Lake Erie took on a sickly green hue. The source of this unnatural greenness — a harbinger of ecological calamity — was a bloom of blue-green algae in the open water. At the same time, beaches became covered in green, slimy, rotting masses of a filamentous algae called *Cladophora.* In deeper water, the decomposition of algae that had fallen to the lake bottom consumed oxygen, rendering the lake oxygen depleted (anoxic). Mayflies and other species disappeared and were replaced by less desirable species, such as sludge worms. Algae fouled fish spawning shoals. There was a precipitous decline in resident aquatic life, which led to the suggestion that Lake Erie was "dying." Ironically, it was suffering from too much life, in the form of algae, due to nutrient-rich, or eutrophic, conditions.

The process of fertilization that causes high productivity and increased biomass in an aquatic system is called eutrophication. The addition of nutrients, such as phosphorus, nitrogen, and potassium, results in rapid growth of algae, in the same way that lawn fertilizers fuel green growth. In the case of the lower Great Lakes and a number of bays and channels, the aquatic ecosystem as it had been in the past was being replaced by a new one.

Everyone had always assumed that, because of their vastness, only local areas of the lakes could be altered by human activities — not whole lakes. Algal blooms on Lake Erie disabused planners of that comforting theory and, in 1972, led Canada and the United States to sign the first Great Lakes Water Quality Agreement. It sought control of phosphorus loadings through the reduction of phosphorus in laundry detergents and reductions of phosphorus from point sources — that is, identifiable, distinct sources, such as municipal sewage outfalls and industrial effluent pipes.

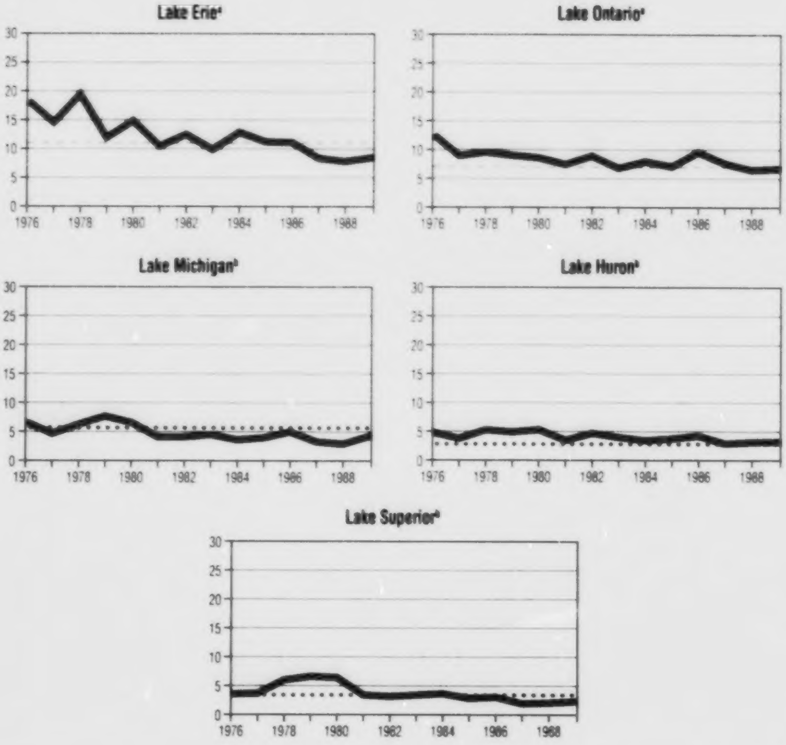
Loadings at point sources have been dramatically reduced since 1972, primarily through upgrading sewage treatment plants (International Joint Commission 1987*a*). To date, over $9 billion has been spent by the Canadian and U.S. governments, and major loading reductions have been achieved — a major international success.

With many point sources showing improvements, the program was strengthened in 1983 through commitments to curtail inputs from non-point sources, such as agricultural drainage and urban runoff. Inputs from such non-point sources are both technically and socially difficult as well as costly to control, and, as a result, it will take much longer to achieve significant reductions.

Decreasing open lake concentrations of total phosphorus clearly reflect substantial reductions in phosphorus loadings

FIGURE 18.6

Estimated total phosphorus loadings in thousands of tonnes in the Great Lakes



[a] Dashed lines represent the phosphorus loadings required for Lake Erie (11 000 t/year) and Lake Ontario (7 000 t/year) to meet the goals set in the Phosphorus Load Reduction Supplement to Annex 3 of the 1978 Great Lakes Water Quality Agreement.

[b] Dotted lines represent loadings that would result if all municipal plants over 3.8 million litres per day limit their phosphorus discharges to 1 ppm. To achieve this goal, the load targets for Lake Huron, Lake Michigan, and Lake Superior would be 2 800, 5 600, and 3 400 t/year, respectively.

Source: Provided by Dave Dolan, International Joint Commission, Windsor.

(Fig. 18.6). Lake Erie, the southernmost, warmest, and most productive of the Great Lakes, shows the most significant recovery from eutrophication, with a roughly 60% reduction in phosphorus levels since 1983 (Fig. 18.7). Although massive algal blooms no longer occur, oxygen depletion in deep waters remains a concern.

Although the phosphorus concentrations in open waters have improved significantly over the past 20 years, many localized nearshore areas still suffer from nutrient enrichment. Of 43 severely degraded Areas of Concern identified by the International Joint Commission, 32 are characterized by elevated levels of phosphorus, including 13 of 17 Canadian Areas of Concern, and 21 are characterized by dissolved oxygen depletion in the water (International Joint Commission 1987*a*). Many inland lakes and tributaries also remain degraded due to nutrient enrichment. This is the case in southwestern Ontario and on the United States side of the Great Lakes basin, where agriculture is intense and where small communities continue to discharge untreated sewage (Colborn *et al.* 1990).

Although the phosphorus problem has stabilized over the last two decades, the concentration of nitrogen compounds has been increasing in all of the lakes and is itself now the cause of growing concern (Fig. 18.8). The increase in nitrogen compounds in the lower Great Lakes appears to be mainly due to increased fertilizer use, while in the upper Great Lakes, direct atmospheric deposition (e.g., acidic precipitation) appears to be the most significant cause (Barica 1987).

The current shift in the ratio of nitrogen to phosphorus could affect the phytoplankton community and have far-reaching effects on food web dynamics (International Joint Commission 1989). The fear is that if phosphorus controls were relaxed, excess nitrogen now in the system could initiate another round of serious eutrophication (Bennett 1986).

Eutrophication, or phosphorus/nitrogen enrichment, represents a simple stress–response mechanism, where the chemical stress and subsequent biological response can be clearly identified. It was the biological response — rotting piles of algae on the beaches and the disappearance of other aquatic life — that ultimately inspired action. People controlled the stress, and, in turn, the ecosystem.

Toxic contaminants

The International Joint Commission has identified in the waters of the basin 362 chemicals that are potentially toxic — a veritable chemical soup. These chemicals can be toxic to plants, animals, and humans. Eleven substances (Table 18.6) have been labelled "critical pollutants… capable of producing adverse, often irreversible effects in a wide range of mammalian and aquatic species" (International Joint Commission 1987*a*). Plants and animals tend to take up and store toxic contaminants in their tissues (bioaccumulation); contaminants also tend to concentrate at higher levels of the food chain (biomagnification). As a result, the threat that toxic contaminants pose to human health and the aquatic ecosystem is significantly enhanced. All 11 persist at unacceptable levels, and therefore the International Joint Commission has placed them on a "primary track."

The task of cleanup and control is daunting. There are a vast number of sources of toxic contaminants: industry, municipalities, and individuals daily pump more chemical contaminants into the system, adding to an already bewildering array.

In certain areas of the Great Lakes, chemicals other than those on the International Joint Commission's "primary track" have been identified as problematic. In its 1990 update, the Niagara River Coordinating Committee established the presence in, or input to, the Niagara River of 342 chemicals; 17 persistent chemicals that were found to exceed the most stringent criteria were assigned priority for immediate action, and 70 others were listed for monitoring on a weekly basis (Niagara River Coordinating Committee 1990). For many of these, implications for both the environment and human health are poorly understood. For Lake Ontario, data for 42 are available and have been assessed. Of these, 11 exceed standards and have been flagged for priority action. These "priority toxic contaminants" are on the International Joint Commission's "critical pollutant" list (Lake Ontario Toxics Committee 1989). There are many more chemicals in Lake Ontario, and an exercise is under way to produce a full inventory.

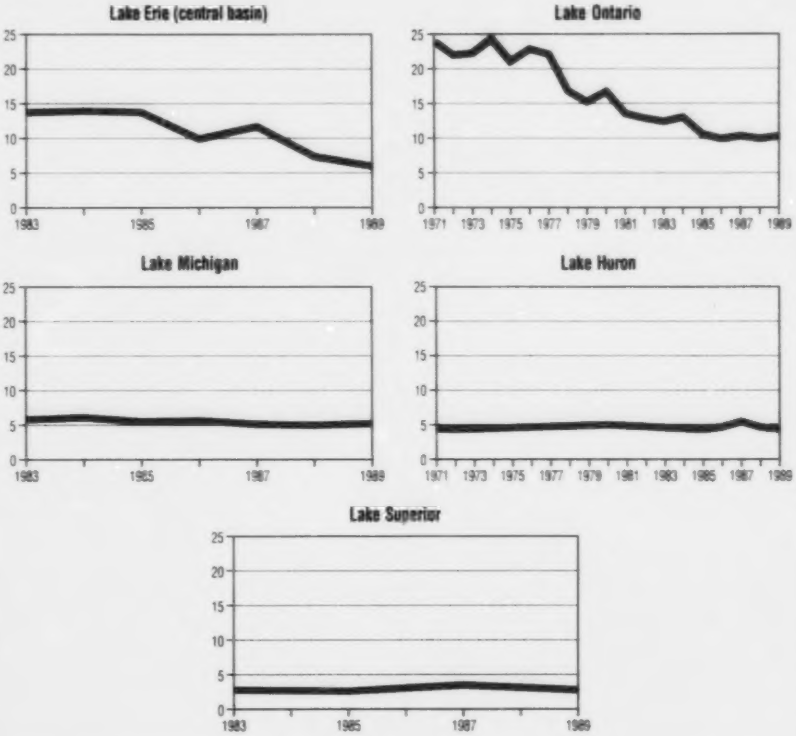
Compiling inventories of chemicals present in the system is only the first, though formidable, task faced by those charged with assessing the state of the ecosystem. Answering the questions of whether contaminants are increasing or decreasing in the system, and what impact their presence is having on the living community, presents a more complex challenge.

Loadings: tracking contaminants

Somewhere in the bedrock outside the toxic waste dump at Hyde Park, in Niagara Falls, New York, are between 36 and 75 t of PCBs, moving inexorably toward the Niagara River. Someday this chemical burden will arrive, adding to the toxic load already in the Great Lakes system and the St. Lawrence River downstream.

FIGURE 18.7

Total phosphorus concentrations in parts per billion in the open waters of the Great Lakes



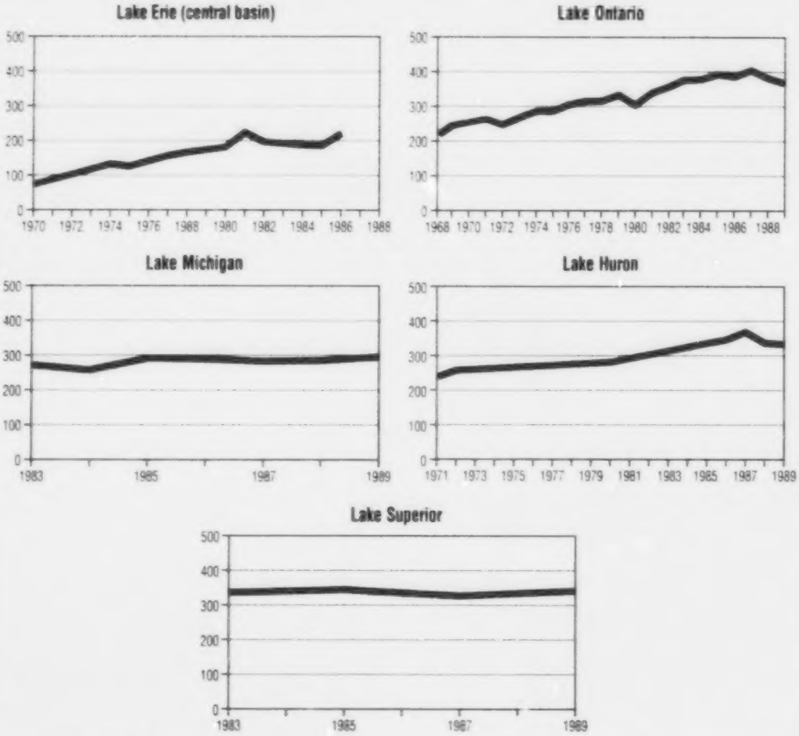
Source: Provided by Dave Dolan, International Joint Commission, Windsor.

Chemical pollutants cycle through the ecosystem — entering, migrating, and exiting by a variety of pathways (Table 18.7). In principle, it should be possible to follow the fate of a pollutant through the system. One means devised to track contaminants is the "mass-balance" model that combines estimates of contaminants entering the system, in the system, and exiting the system. If inputs exceed outputs, pollutants are accumulating and contaminant levels are rising. Scientists have completed initial mass-balance calculations for four of the International Joint Commission's critical pollutants: PCBs, alkylated lead, benzo(a)pyrene, and DDT (International Joint Commission 1987*b*).

Unfortunately, a lack of hard data limits the practical application of the mass-balance approach. Though monitoring being conducted in Ontario under the Municipal/Industrial Strategy for Abatement (MISA) will dramatically improve the point-source-to-surface-water data base for the Canadian side, significant data gaps will still remain, particularly related to non-point discharges (urban and agricultural runoff, groundwater discharge, atmospheric deposition). To set meaningful priorities for reduction of contaminants, it is necessary to know the relative inputs from all sources — and we do not yet have that information. Data now available are limited to specific activities or to a limited geographic area. For example, the Great Lakes Water Quality Board of the International Joint Commission has had to estimate the loadings of contaminants from municipal sewage treatment plants based on

FIGURE 18.8

Nitrite plus nitrate concentrations in parts per billion in the open waters of the Great Lakes



Source: Provided by Dave Dolan, International Joint Commission, Windsor.

extrapolation of data from only 20% of the 1 199 municipal plants that discharge directly to the Great Lakes (Table 18.8). Data are for 1985, and no historic trends are available.

The binational Upper Great Lakes Connecting Channels Study compiled a summary of loadings from major point, non-point, and tributary sources to the St. Marys, St. Clair, and Detroit rivers (Upper Great Lakes Connecting Channels Study, Management Committee 1988). This study revealed that point sources are the largest contributor of most contaminants, even though most discharges are regulated, and combined sewer overflows are major sources of contaminants to the connecting water bodies. Non-point loadings, particularly from agricultural and urban runoff, can be locally significant, although the study found that these inputs have not been adequately quantified.

No situation better illustrates the current uncertainty in assessing the extent of toxic contamination of the system than the discharge of toxic contaminants from hazardous waste sites to the Niagara River. A preliminary estimate of these loadings was first attempted in 1988 (Gradient Corporation and GeoTrans Inc. 1988). On the American side, 215 hazardous waste disposal sites are located within the Niagara River drainage basin. Of these, 164 are within 5 km of the river. There are 70 sites in 30 "clusters" that pose a threat to the Niagara River. These sites contribute 315 kg of toxic chemicals to the river daily. The data upon which these estimates are based are limited, and the loading could in fact be significantly higher. The four major Superfund sites in the area (Love Canal, 102nd Street, S-Area, and Hyde Park) alone contain 304 000 t of chemical waste. All are connected by groundwater to the Niagara River, and all are characterized by off-site movement of contaminants, as in the case of Hyde Park (Brooksbank 1987). Eight other sites have some potential for off-site migration of toxic substances or are linked by groundwater to Lake Erie or the Niagara River. None of the 17 sites on the Canadian side of the river is believed to contribute toxic chemicals on the priority action list to the Niagara River (M. Goffin, Environment Canada, personal communication).

Table 18.9 summarizes a preliminary assessment of point and non-point contaminant loadings to the Niagara River. Using the "best estimate" of groundwater loadings, the current contribution of contaminants via groundwater can be seen to be roughly equal to the current contribution from all point sources combined — and this does not include contaminants in groundwater from below operating plants adjacent to the Niagara River, which may also be a significant problem.

It should be obvious from these examples that the data base on contaminant loadings is limited. In many instances, we do not know where the contaminants are coming from or where they are going. The issue of loadings highlights a significant weakness in the management regime for the entire Great Lakes basin. That being said, the river monitoring program for the Niagara River provides some of the best quantification of toxic chemicals in North America.

Biomagnification of contaminants

Levels of contaminants in surface waters tell only part of the story with respect to toxic contaminants and the health of the ecosystem. To begin with, molecules of contaminants do not generally persist for long as independent, free-floating entities in surface waters (Mackay 1989). If they are not destroyed, they either attach themselves to particles (living or nonliving) and become part of the bottom sediments, or are ingested and become part of the food web. In these ways, they move from one medium to another and cycle through the system.

PCBs offer a good example of the concerns related to bioaccumulation and biomagnification of toxic contaminants. PCB concentrations in the water may be so low as to be undetectable. However, as a water flea filters water for its food of phytoplankton, it may collect in its tissues 400 times the concentration of PCBs in the water. A water flea is eaten by a shrimp, which is swallowed by an alewife, which in turn is consumed by a Herring Gull or a larger lake trout. The concentration of contaminants is boosted tens to hundreds of times at each level of the food chain. By the time the PCBs have passed through these successive levels of the food web and been deposited in the Herring Gull's egg, the concentration of the dangerous substance may have biomagnified by 10 million times the levels detectable in the water.

Bioindicators: signs from wildlife

Often, a better indicator of the state of the aquatic ecosystem than contaminant levels in the surface waters themselves is the concentration in bottom sediments or in the tissues of indicator species of algae, fish, birds, and mammals (see Box 18.1). Images of Great Lakes fish with tumours and advisories warning people not to eat certain species of fish are potent reminders of the toxic threat lurking in Great Lakes waters. Figures 18.9 and 18.10 show the trends in PCB concentrations in lake trout and Herring Gull eggs, respectively. The conditions of these living organisms also act as barometers of ecosystem health. Thus, the presence of tumours in a broad range of fish species, in particular brown bullhead, white sucker, and slimy sculpin, can be taken as a strong sign of ecosystem degradation. Table 18.10 summarizes contaminant analyses involving 15 Great Lakes species and, by using bioindicators, provides a broad picture of conditions in the lakes.

Despite the association between health effects and concentrations of contaminants, it is difficult to prove that particular contaminants have caused specific effects in wildlife populations. These chemicals sometimes act in an additive or synergistic way, sometimes they counteract each other (are antagonistic), and sometimes they do not interact at all. The impact of these complex and poorly understood chemical relationships is further complicated by the physical and chemical stresses discussed earlier (Table 18.3).

TABLE 18.8

The 11 "critical pollutants" on the International Joint Commission's "primary track"

Chemical	Production and release	Source
TCDD	Unintentional	Created in the manufacture of herbicides used in agriculture, and range and forest management. Also produced as by-products of combustion of chlorinated additives in fossil fuels and chlorine-containing wastes, through production of pentachlorophenol (PCP), and in pulp and paper production processes that use chlorine bleach. TCDD is the most toxic of 75 congeners (forms) of polychlorinated dibenzodioxins, and TCDF is the most toxic of 135 congeners of polychlorinated dibenzofurans.
TCDF	Unintentional	
Benzo(a)pyrene	Unintentional	Product of incomplete combustion of fossil fuels and wood, including forest fires, grills (charcoal broiling), auto exhausts, and waste incineration. One of a large family of polycyclic aromatic hydrocarbons (PAHs).
DDT and its breakdown products, including DDE	Intentional	Insecticide used heavily for mosquito control in tropical areas.
Dieldrin[a]	Intentional	Insecticide used extensively at one time, especially on fruit.
HCB	Unintentional	By-product of combustion of fuels that contain chlorinated additives, of incineration of wastes that contain chlorinated substances, and of manufacturing processes using chlorine. Found as a contaminant in chlorinated pesticides.
Alkylated lead	Intentional	Used as a fuel additive and in solder, pipes, and paint.
	Unintentional	Released through combustion of leaded fuel, waste, and cigarettes, and from pipes, cans, and paint chips.
Mirex[b]	Intentional	Fire retardant and pesticide used to control fire ants. Breaks down to more toxic form, photomirex, in presence of sunlight. Present sources are residuals from manufacturing sites, spills, and disposal in landfills.
Mercury	Intentional	Used in metallurgy.
	Unintentional	By-product of chlor-alkali, paint, and electrical equipment manufacturing processes. Also occurs naturally in soils and sediments. Releases into the aquatic environment may be accelerated by sulphate deposition (i.e., acidic deposition).
PCBs[c]	Intentional	Insulating fluids used in electrical capacitors and transformers and in the production of hydraulic fluids, lubricants, and inks. Was previously used as a vehicle for pesticide dispersal. PCBs comprise a family of 209 forms of varying toxicity.
	Unintentional	Primarily released to the environment through leakage, spills, and waste storage and disposal.
Toxaphene[a]	Intentional	Insecticide used on cotton. Substitute for DDT.

[a] Use restricted in the United States and Canada.

[b] Banned for use in the United States and Canada.

[c] Manufacture and new uses prohibited in the United States and Canada.

Source: Colborn *et al.* (1990).

TABLE 18.7

Contaminant sources to the Great Lakes and connecting water bodies and exit mechanisms from the system

1. **Sources of direct entry:**
    - point source discharges, such as industrial and municipal effluent
    - non-point source discharges, such as agricultural and urban runoff
    - internal "reentry" from bottom sediments
    - atmospheric deposition
    - spills and accidental releases
2. **Sources of indirect entry:**
    - point and non-point discharges to tributaries, inland lakes, and groundwater that subsequently enter the surface water system
    - emissions to air that subsequently reach the system
3. **Exit mechanisms:**
    - outflow via the St. Lawrence River
    - discharge to the atmosphere
    - biomass of fish and other wildlife harvested

The most unequivocal cause-and-effect relationship between wildlife reproduction and survival and a specific chemical is the case of DDT, which has been shown to cause eggshell thinning (Noble 1990). The Great Lakes population of Double-crested Cormorants declined seriously from the late 1940s to 1975 due to DDT-induced eggshell thinning. Control of DDT has resulted in population recovery: the increase in cormorant nests observed in the 1980s coincides with the decline of DDE (a breakdown product of DDT) concentrations in their eggs. Despite population increases, disturbingly high numbers of birth deformities — club feet, shortened appendages, missing eyes, missing brains, major organs outside the body, and bill defects — are still occurring in highly contaminated areas like Green Bay and Saginaw Bay in the United States (Colborn 1988).

DDT-induced eggshell thinning also caused Black-crowned Night-Herons and Bald Eagles to suffer population declines. With decreased DDT levels in the environment, Black-crowned Night-Herons rebounded in the late 1970s. However, levels remain high in Bald Eagles. In the Lake Ontario basin, the recovery of shoreline populations has been further hindered by the destruction of suitable habitat. Currently, there are no Bald Eagle nests along Lake Ontario itself.

Though positive linkages between contaminants and observed effects can rarely be proven, the evidence for links is often compelling. A study in 1988 showed that the shoreline populations of 16 predator species, including mink, have dropped in association with high levels of toxins (Colborn 1988).

In some instances, biologists have been able to propose plausible mechanisms for the action of toxic contaminants in wildlife populations. For instance, toxic chemicals are thought to have caused two major dieoffs of Ring-billed Gulls, in 1969 and 1973. Deaths occurred at the end of the breeding season when, it is hypothesized, a food shortage caused the birds to mobilize residues from body fats where the toxic chemicals had bioaccumulated. Populations began to expand in the late 1970s and today seem to be thriving.

In the 1960s, ranch mink fed on a diet of Great Lakes fish suffered complete reproductive failure. Research showed that PCBs with dioxin-like properties were related to the adverse effects on the adults and fetuses. High residue levels of the organochlorines PCBs, HCB, chlordane, and DDE were detected in the turtles of Hamilton Harbour (1984–89), as compared to a control site in Algonquin Park. Eggs were incubated, and deformities similar to those observed in cormorants, gulls, and terns were noted. There were significant associations with PCBs at some sites, although there was no overall correlation with any single contaminant (Government of Canada 1991).

The effects of toxic contaminants are ecosystem-wide and, in fact, extend outside the boundaries of the basin proper. The biological system of the St. Lawrence is continuous with that of the Great Lakes, and many of the effects of chemical contamination of fish and wildlife that are found in the Great Lakes have also been observed in the St. Lawrence. Levels of the contaminants mercury, PCBs, DDT and its metabolites, mirex, dieldrin, and HCB in seabird eggs in the Gulf of

BOX 18.1

Herring Gull: symbol and sentinel

In 1971, a biologist made a disturbing discovery at Scotch Bonnet Island in Lake Ontario. Where there should have been 100 Herring Gull chicks, he found only 12. Since that time, the reproductive problems of the hearty and ubiquitous Herring Gull have become a symbol of the problems afflicting wildlife in the Great Lakes ecosystem.

A program begun in the early 1970s to monitor persistent toxic chemicals in the eggs of Herring Gulls showed that water birds in the Great Lakes were among the most heavily contaminated in the world. High levels of chlorinated organic contaminants in eggs of Herring Gulls coincided with high embryonic mortality and behavioural changes in adults, such as inattentiveness, which resulted in lower hatching success and physiological abnormalities in the embryos and chicks.

Contaminants in Herring Gull eggs have declined since that time, largely due to regulations implemented in the late 1960s and early 1970s on the use and production of chlorinated organic compounds. However, the rate of contaminant decline slowed in the 1980s, and in 1981 and 1982 actually showed a brief increase (Fig. 18.10), indicating that persistent contaminants are still cycling through the ecosystem from less easily controlled sources, such as leaching from landfill sites, disturbance of lake sediments, and deposition from the atmosphere. Monitoring of contaminant levels in Herring Gull eggs will continue, as they serve as sentinels for the presence of biologically significant concentrations of chemicals in the Great Lakes.

Source: Bishop and Weseloh (1990).

St. Lawrence are only one-third those found in the Great Lakes. This suggests downstream dilution and reduction of contaminant levels and a parallel reduction of influence from upstream sources, one of which is the Great Lakes.

However, the plight of organisms higher in the food web, in particular the beluga (white whale) (see Chapter 19), suggests that bioaccumulation processes counteract this simple dilution. The beluga population in the St. Lawrence estuary has been reduced to approximately 10% of its estimated size in the late 1800s. Whales are currently dying in middle age, at 14–15 years, compared to a normal life span of 30 years. Among the 25 toxic chemicals so far discovered in these whales are 8 of the 11 critical pollutants designated by the International Joint Commission's Great Lakes Water Quality Board (Table 18.6). Of particular significance is the presence of mirex and its decay product, photomirex. So far as it is known, no mirex was ever produced along the St. Lawrence River or the St. Lawrence estuary, although there are two major sources in the Great Lakes basin. The link appears to be American eels, which accumulate the mirex in or near Lake Ontario, migrate downstream, and subsequently form a significant part of the whales' food supply. Thus, through bioaccumulation, species migration, and biomagnification, a distant contaminant source may have extremely potent effects. Much more work is required to confirm this sequence of processes.

Although more research is required to elucidate the cause-and-effect relationship between chemicals and toxic effects in wildlife, it is clear that persistent contaminants that cycle through the ecosystem and food web have disabling effects on many species. Poor reproductive success, deformed young, and reduced survival of offspring have been observed in predators near the top of the food web, including Ospreys, ranch mink, Bald Eagles, gulls, terns, cormorants, lake trout, and snapping turtles.

TABLE 18.8

Estimate of total release and distribution of contaminants from municipal sewage treatment plants in the Great Lakes basin, 1985

Contaminant	% of total release emitted via Effluent	Atmosphere	Disposal[a]	Total release (t/year)
a) Metal				
Arsenic	66	NS[b]	34	19.0
Cadmium	76	NS	24	26.0
Chromium	49	NS	51	640.0
Copper	43	NS	57	300.0
Lead	59	NS	41	580.0
Mercury	44	NS	56	2.7
Nickel	79	NS	21	130.0
Zinc	51	NS	49	1 300.0
b) Chemical compounds				
Base-neutral extractable PAHs				
Anthracene	NE	NE[c]	NE	NE
Naphthalene	53	20	28	28.0
Benzene	61	39	NS	2.4
Chloroform	70	30	NS	34.0
Cyanide	73	NS	27	89.0
Ethylbenzene	31	69	NS	55.0
HCB	NS	25	75	0.04
PCBs (total)	50	NS	50	0.3
Phenol (total)	94	NS	6	85.0
TCDD	NE	NE	NE	NE
TCDF	NE	NE	NE	NE
Tetrachloroethylene	36	64	NS	76.0
Toluene	45	55	NS	42.0
1,1,1-Trichloroethane	49	51	NS	76.0
Trichloroethylene	58	42	NS	26.0

[a] Via landfill or land application.
[b] NS = Assumed to be "not significant."
[c] NE = No estimate.
Source: International Joint Commission (1989).

"Our fate is connected to the animals," Rachel Carson wrote in her 1962 classic, *Silent spring*. For the residents of the Great Lakes basin, this warning might well have disturbing relevancy. It is naive to suppose that humans, who are also high in the food web (we consume fish such as lake trout, for example), have not suffered, or will not suffer in the future, some adverse effects as a result of prolonged exposure to toxic contaminants.

Implications for human health

Marathon swimmer Vicki Keith aborted her 1990 triple crossing attempt of Lake Ontario because the pollution was so noxious that it caused her to vomit violently. "I have never seen pollution as bad as in Lake Ontario. I'm worried about going in there and risking my life," the swimmer remarked on returning to shore.

Many residents of communities along the Great Lakes, in areas where toxic contaminant concentrations are high and persistent, share Keith's trepida-

TABLE 18.9

Point and non-point loadings of toxic contaminants to the Niagara River, 1986 and 1987

Loading	kg/day
Point source	
United States (total 1986)[a]	245
Canada (total 1987)[b]	62
Non-point source (groundwater)	
United States (total 1987)[c]	
• best estimate	315
• low estimate	53
• high estimate	2 075
Canada	not available

[a] Department of Environmental Conservation (1987)
[b] Ontario Ministry of the Environment (1987)
[c] Gradient Corporation and GeoTrans Inc. (1988)

tion. Naturally, they want to know whether the air they breathe, the water they drink and bathe in, and the food they eat are safe. Unfortunately, current knowledge can provide only partial answers to these vexing questions.

For humans, the major contaminant exposure route is through the consumption of food; air and water contribute only 10 and 15% respectively of our daily exposure. In turn, the purity of food depends on the quality of all components of the ecosystem — water, air, and soil.

Our bodies now contain a large number of contaminants that are environmentally persistent and have biomagnified through the food web. For example, in Canada and the United States, dioxins (by-products of the manufacture or combustion of chlorinated organic compounds, some of which are extremely toxic to laboratory animals) are generally found in all human fat tissue. For the Great Lakes basin, the limited human tissue residue data indicate that the general population is probably not exposed to higher levels of the most common persistent contaminants than residents of other parts of North America. Nonetheless, certain Great Lakes subpopulations are at elevated risk, particularly those who depend on food higher in the food web, such as the breast-fed infants of mothers who consume large quantities of locally caught fish and wildlife.

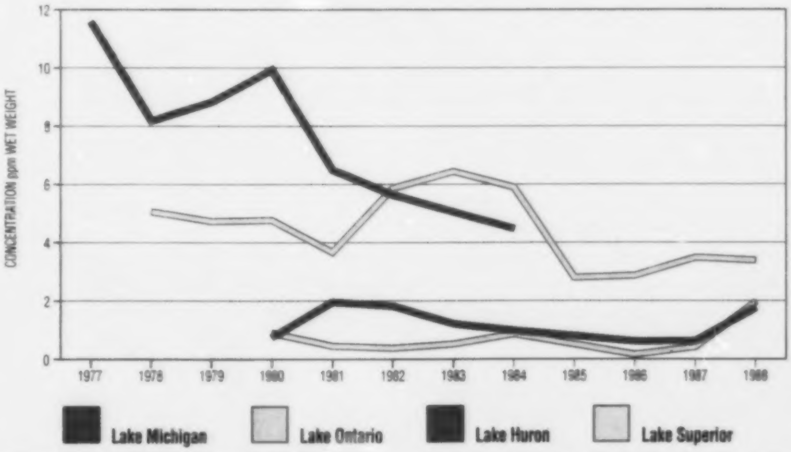
Wildlife studies indicate that it is the offspring of exposed adults that suffer most of the problems. This is cause for particular concern in the human population. Due to the relatively long period between birth and child bearing, women can accumulate significant amounts of toxic substances, which they then pass on to their offspring through the placenta or breast milk (Colborn *et al.* 1990).

Gross birth defects and cancer have often been viewed as indicators of contaminant stress. As tools, however, they are too blunt to detect the more subtle effects of exposure to chemical contaminants. Researchers currently have a special interest in the subtle changes that can occur in a developing fetus of a woman who has had a lifetime exposure to contaminants. One study, conducted among Lake Michigan pregnant women, found a moderately significant correlation between the consumption of more than 0.5 kg of Lake Michigan fish per month and umbilical cord serum PCB levels. Their newborns showed a significantly higher percentage of decreased birth weight, head circumference, and neurobehavioural development. Psychological tests administered to the same children at age four indicated that they were experiencing learning problems. These types of disturbing effects, passed from one generation to another, are currently the focus of research, but additional research on long-term, low-level exposure is needed. In particular, more needs to be known about how different contaminants combine to produce additive or synergistic effects. Assessment of the correlation between effects monitored in fish and wildlife and those measured in humans may eventually lead to important revelations.

In the meantime, governments have adopted preventative health measures. The Government of Ontario publishes a *Guide to eating Ontario sport fish*, which provides guidelines for consumption of both inland and Great Lakes fish (Ontario Ministry of the Environment and Ministry of Natural Resources 1991). The guidelines identify fish species, sizes of fish, and locales in which fish are too contaminated to be eaten. Between 1983 and 1991 there was little change within lakes Superior and Ontario in the number of sites having such advisories, although the Ontario Ministries of the Environment and of Natural Resources

FIGURE 18.9

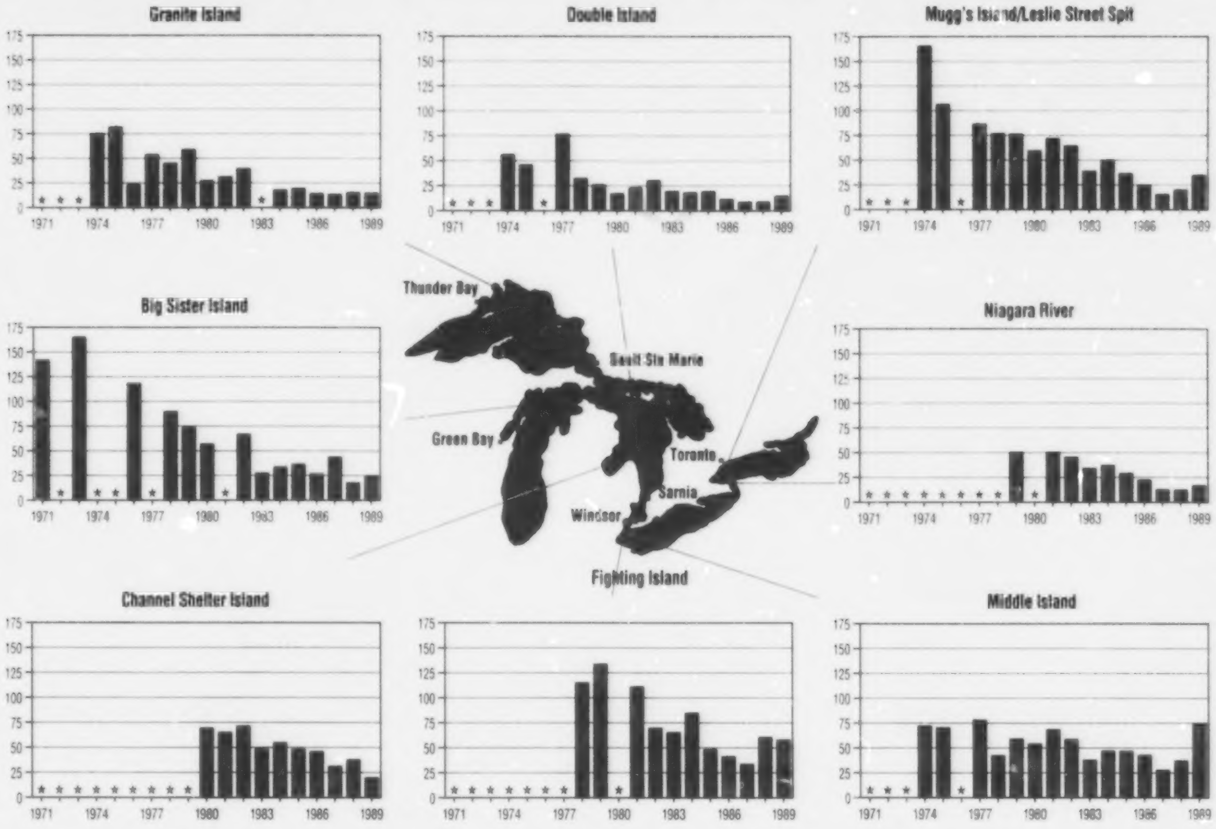
Mean concentrations of PCBs in whole Great Lakes lake trout, 1977–88



Source: Government of Canada (1991).

FIGURE 18.10

Concentrations of PCBs in parts per million in Herring Gull eggs throughout the Great Lakes, 1971–89



*No data.

Source: Bishop and Weseloh (1990).

have found some reductions in the concentration of contaminants in fish in Lake Ontario.

Such advisories must be viewed as stopgap measures only, designed to break the chain of events leading to risk to human health. In the long term, the only alternative is greater commitment to research, especially on the effects of long-term, low-level exposure, and to the reduction of exposures through control of contaminants at the source.

Trends in toxic contaminants

Although there are hundreds of potentially deleterious chemicals in the Great Lakes ecosystem, no new contaminants that fit the criteria of widespread occurrence, high toxicity, and persistence have been detected in any of the Great Lakes since the early 1980s. Water and bottom sediment samples, as well as indicator species of algae, fish, and other wildlife, consistently showed a general reduction in contaminant levels during the 1970s. This reduction has now levelled off. These findings suggest that, while the scale of problem related to toxic contaminants will likely never be as bad as it once was, further controls of loadings will be required if levels are to drop any further (Government of Canada 1991).

With local exceptions, lakes Ontario, Michigan, and Erie and the connecting water bodies continue to be more severely degraded than lakes Superior and Huron. Lake Ontario, situated at the bottom of the system, receives the cumulative toxic load from all water bodies above it and, predictably, is the most degraded. The highly contaminated Niagara River accounts for more than 50% of its toxic loadings. Figure 18.11 provides an overview of the current status and trends in toxic contamination for the Great Lakes system.

Unfortunately, the problem of toxic contaminants is far from being resolved. Although reductions have occurred, the rate is slowing, and, in the case of Lake Ontario, concentrations may be stabilizing at unacceptably high levels. Causes are related to continuing contaminant sources: a variety of

TABLE 18.10

Effects on populations, organisms, and tissues found in Great Lakes animals[a]

Species	Population decrease	Effects on reproduction	Eggshell thinning	Congenital malformations	Behavioural changes	Biochemical changes	Mortality	Alterations in recruitment
Mink	X	X	NA	NE	NE	NE	X	?
Otter	X		NA	NE	NE	NE	?	?
Double-crested Cormorant	X	X	X	(X)		X	?	?
Black-crowned Night-Heron	X	X	X	X		X	?	?
Bald Eagle	X	X	X	NE		NE	NE	?
Herring Gull		X	X	X	X	X	X	
Ring-billed Gull				X		NE	X	
Caspian Tern		X		X	NE	NE		X
Common Tern		X	X	X		X		
Forster's Tern		X		X	X	X		
Snapping turtle	NE	X	NA	X	NE	NE	NE	NE

[a] X = effects documented. NA = not applicable. NE = not examined. ? = suspected since population declined.

Note: Observations marked with an X have been reported in the published literature; unpublished records of congenital malformations exist for the Double-crested Cormorant, Great Blue Heron, and Virginia Rail.

Source: Government of Canada (1991).

municipal and industrial point sources, atmospheric inputs, groundwater discharge from waste sites, and recirculation from bottom sediments together are combining to maintain contaminant levels in the system.

The fisheries

"Stores of fishes, sturgeons of vast bigness, and Pykes seven feet long," enthused the *coureur des bois* Pierre Radisson, when writing about the fishery resource of Lake Superior in 1658.

Fish are an important part of the Great Lakes ecosystem and, like other natural resources in the basin, have significantly contributed to the well-being of its residents. The Great Lakes support commercial, sport, and native subsistence fishing, and fishing is big business. The gross economic value of the Great Lakes sport fishery has been estimated at $4 billion annually (Boulanger and Charbonneau 1989). Recently, sport fishing supported by hatchery-produced fish has replaced the commercial fishery as the dominant economic component. In 1988, the landed value of commercial fishing was about $55 million.

In 1985, there were nearly 1 million Canadian anglers on the lakes, up 16% from 1980 (Talhelm 1988). Effort was greatest on Lake Huron, followed by lakes Ontario, Erie, and Superior. Species preferred across all five lakes, in descending order, were walleye, rainbow and brown trout, bass, northern pike, and perch. Despite their high profile with U.S. anglers, exotic (non-native) hatchery-reared salmonids made up less than 6% of the total Ontario catch. Aboriginal catches represented 3% of the total harvest in Ontario.

Changing fish populations

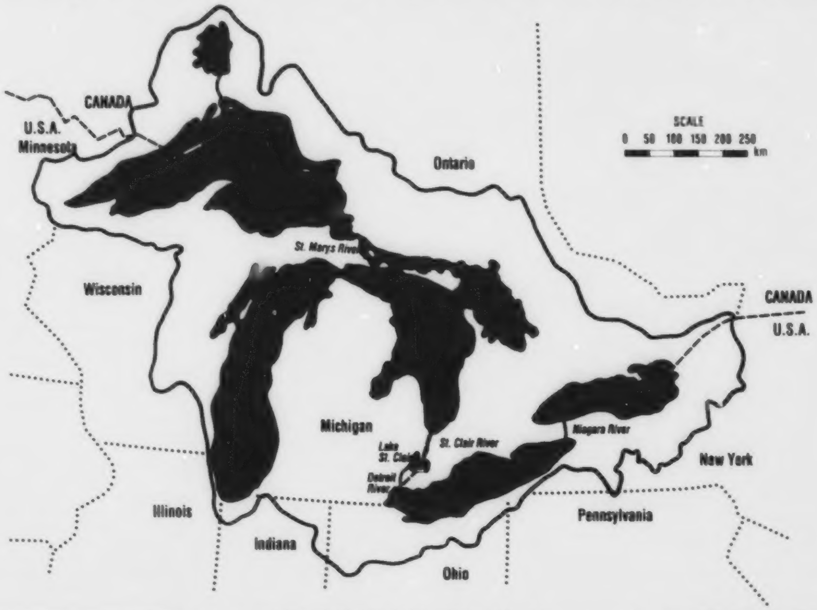
Although fishing has contributed greatly to the economy of the Great Lakes basin and the lifestyle of its residents, it has also imposed a significant stress on the ecosystem. It was the 19th century before full-scale, deepwater exploitation of fish stocks began in earnest, but it was not long in wreaking great changes to the fishery resource.

Prior to the 1900s, fish populations in the lakes were dominated by large, high-value species such as sturgeon, lake trout, lake whitefish, northern pike, muskellunge, walleye, channel catfish, and, in Lake Ontario, Atlantic salmon. The salmon disappeared by 1900 — the victim of destruction of spawning habitat by forestry operations. As late as the 1930s, the commercial catch had a high proportion of high-value fish such as lake trout and chub. By the 1950s, however, overfishing, invasion of the sea lamprey, the introduction of exotic species, shifts in lake chemistry due to both nutrients and toxic contaminants, and habitat loss all combined to cause the near-collapse of many fish populations and their associated fisheries. Today, the high-value species portion of the commercial catch is smaller and less diverse. Further, the smelt and alewife, both exotics, have replaced the herring as the low-value forage fish. Lake herring, important in the early 1900s, is now restricted to Lake Superior.

The marked changes in the nature and mix of Great Lakes fish are reflected in the makeup of the commercial fish catch since the late 1800s. Figure 18.12 reflects a shift, by the commercial fishery, to fish with lower value, as the stocks of higher-value fish declined (Statistics Canada 1986). For example, in the 1880s, practically the entire Lake Superior commercial catch consisted

FIGURE 18.11

Status, trends, and signs of toxic contamination in the Great Lakes and connecting water bodies



Lake Superior

- best overall water quality in the system.
- 90% of contaminants, including chlorinated organic compounds, enter the lake via the atmosphere.
- lowest metal concentrations; lead, mercury, and cadmium levels elevated in some bays and harbours due to discharges from pulp and paper mills, municipal sewage treatment plants, and mining.

St. Marys River (Lake Superior to Lake Huron)

- least degraded of connecting water bodies.
- localized degradation adjacent to and downstream from steel and paper mills and municipal sewage treatment plants on Canadian side.
- mercury in large specimens of some sport fish exceeds objectives of the International Joint Commission.

Lake Huron

- water quality in open waters almost the same as in the early 1800s.
- contamination in harbours and embayments due to local industry, agricultural runoff, and recreational boating in Severn Bay.
- Serpent River drainage basin contaminated by radionuclides and heavy metals from Elliot Lake mining district.
- concentrations of PCBs, dieldrin, and mercury in trout stable since 1985; DDE, HCB, and PCB levels in Herring Gull eggs reduced by approximately half since 1980.

St. Clair River (Lake Huron to Lake St. Clair)

- major improvements in water quality achieved in the 1980s.
- toxic industrial solvents and metals from Sarnia's chemical valley compromise local environmental quality; HCB and perchloroethylene exceed guidelines.
- sediments, containing toxic organic compounds and mercury from chemical valley, lethal to a number of indicator organisms.

Lake St. Clair (St. Clair River to Detroit River)

- water, sediment, and biota quality improved during the 1980s.
- mercury in sediments a concern, though overall level of metals low.
- toxic organic compounds in fish and duck flesh at potentially significant levels.

Detroit River (Lake St. Clair to Lake Erie)

- an International Joint Commission Area of Concern.
- water and sediments degraded in terms of conventional pollutants, toxic organic compounds, and metals, though improvements achieved since the 1970s.
- a range of contaminants in fish, waterfowl, and other wildlife species.
- oral, dermal and liver tumours in fish in the lower Detroit River.

Lake Michigan

- second only to Lake Ontario in overall degradation by toxic contaminants.
- especially degraded by toxic contaminants in south; sediments have highest levels of PAHs and PCBs in the basin; Waukegan Harbour sediments contain 500 000 ppm (50%) PCBs.
- most severe metal contamination (lead, mercury, cadmium, and others) of all the lakes.

Lake Erie

- heavily polluted by lead, mercury, zinc, cadmium, and arsenic, and toxic contamination close to Lake Michigan.
- metals and organic compounds in both open waters and sediments declining due to burial and dilution.
- Detroit and Maumee rivers major sources of organic chemical contaminants, including PCBs; western basin severely degraded.
- contaminant levels lower than expected in fish species, perhaps due to eutrophic state of lake; in 1987, concentrations of PCBs in spottail shiners in western Lake Erie exceeded objectives.

Niagara River (Lake Erie to Lake Ontario)

- an International Joint Commission Area of Concern; main source of toxins for Lake Ontario.
- 261 human-made chemicals in the system; main compounds of concern are DDT, PCBs, mirex, and mercury, as well as dioxins and furans.
- 57 chemicals considered to pose human health or environmental risk.

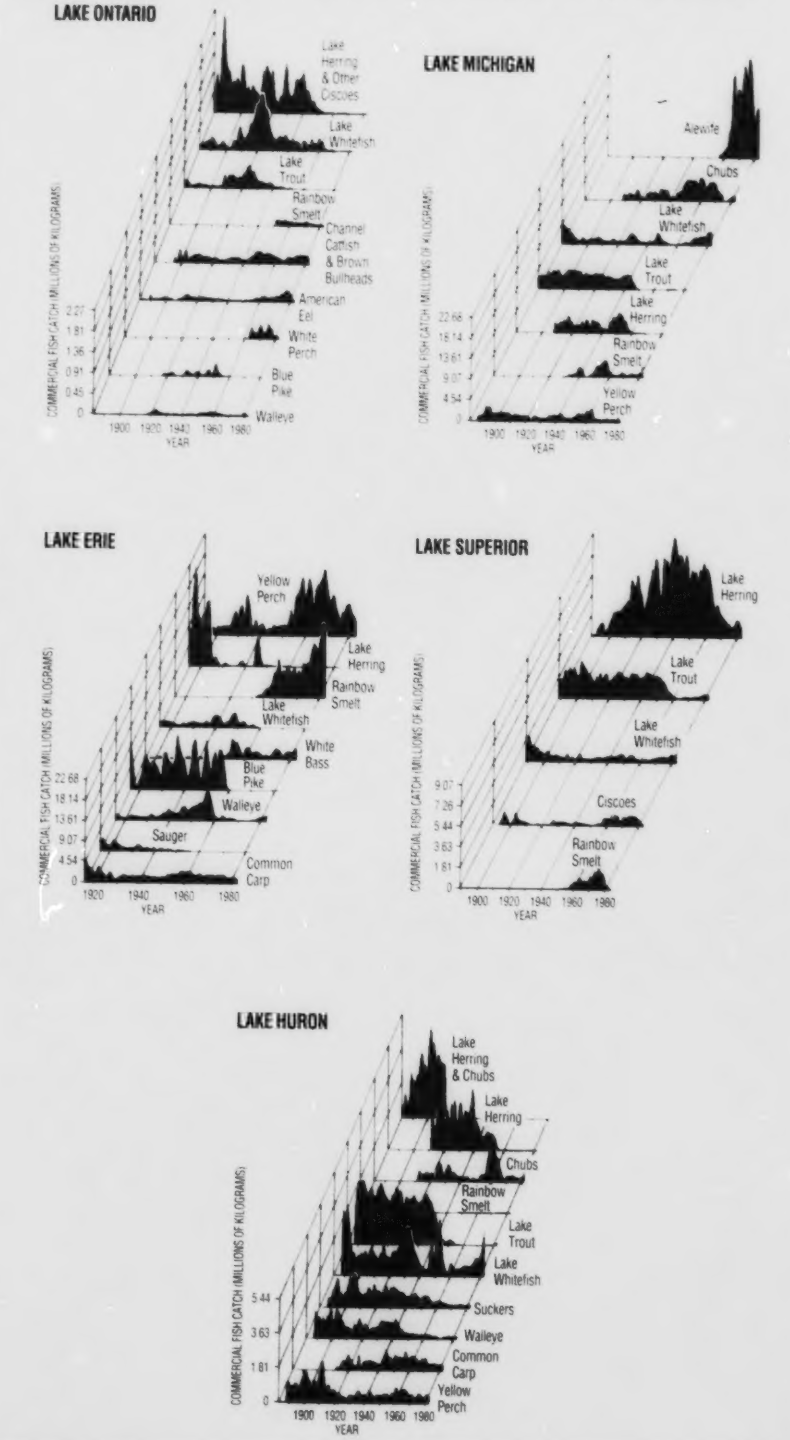
Lake Ontario

- most contaminated lake vis-à vis diversity and concentrations of organic compounds.
- highest mean concentration in open waters of all chlorobenzenes; sediments contain highest concentrations of dioxins and furans; concentrations of problem toxic substances may be stabilizing at unacceptably high levels.
- bioaccumulation of PCBs, TCDD, chlordane, dieldrin, and DDT and metabolites in fish makes them unfit for consumption by other wildlife.
- deformities and reproductive failures in fish-eating birds attributed to toxic contaminants.

Source: Data principally from International Joint Commission (1989) and Upper Great Lakes Connecting Channels Study, Management Committee (1988); modified from an unpublished draft figure, prepared by P. Bircham, Environment Canada, State of the Environment Reporting.

FIGURE 18.12

Trends in commercial fish catches in the Great Lakes, 1880–1986



Source: Hartman (1988).

of lake trout and whitefish. By the 1960s, the proportion of these species had declined to less than 10% (Regier *et al.* 1988).

Extinctions and extirpations of fish species

Sturgeon were once so numerous that people who caught them considered them a nuisance and piled them in great pyres and set them aflame; steamboats actually used them to fire their boilers. Today, they are nearly extirpated in the lakes (Ashworth 1986).

Overexploitation has led to declines and disappearances of fish stocks in the Great Lakes. In Lake Ontario, the number of species extirpations has been high, amounting to over 10% of the estimated 75 fish species that were historically in this lake. The Atlantic salmon was the first victim. Damming and siltation of its spawning habitats wiped this species from Lake Ontario by the late 1800s. The lake trout became extirpated through much of its range, due to overfishing and lamprey predation. With the demise of lake trout stocks, populations of ciscoes were exploited, and overfishing, lamprey predation, and competition from alewife greatly reduced stocks. The alewife was also implicated in the extirpation of Lake Ontario deepwater sculpins and Lake Michigan spoonhead sculpins. The blue walleye (also known as blue pike), endemic to lakes Erie and Ontario, was fished to extinction. Thirteen species of fish native to the Great Lakes basin are currently listed by the Committee on the Status of Endangered Wildlife in Canada as either extinct, extirpated, endangered, or threatened.

Exotics

Just as populations of some species have declined or disappeared altogether from the lakes, so new species have appeared. When, in 1919, engineers deepened the Welland Canal, linking Lake Ontario to Lake Erie, they inadvertently provided an improved way upstream for the parasitic sea lamprey — an ancient fish, sporting a mouth like a suction cup arrayed with teeth that it uses to attach itself to fish. The arrival of the lamprey spelled doom for the once-numerous lake trout.

Exotic species have been both deliberately released and accidentally introduced into the lakes, and they have had both positive and negative effects on the ecosystem. Table 18.11 lists species introduced to the Great Lakes. Stocking of Pacific salmon and rainbow trout has produced significant sport fisheries throughout the Great Lakes, while fishing pressure has simultaneously shifted away from the lake trout, a species currently targeted for, but responding poorly to, rehabilitation. Commercial fisheries exist for several exotics, including pink salmon, common carp, white perch, and rainbow smelt. Invading species have affected native species, both directly through predation and indirectly through competition. There is strong evidence that rainbow smelt are competing with and preying on whitefish and lake herring. Alewife have had more extensive effects because they compete with and prey on the young of bloaters, deepwater sculpins, spoonhead sculpins, yellow perch, lake herring, rainbow smelt, and emerald shiners. Alewife and smelt have also had positive effects on the ecosystem and today comprise a major portion of the diet for salmonids, both exotic and indigenous.

The sea lamprey, after invading the upper Great Lakes in the 1930s, had a devastating effect on the fisheries, which included the virtual elimination of the lake trout in all of the lakes except Superior. Chemical controls are partially successful, but occasionally kill fish of other species. Several other forms of control are now being considered, one of which is the release of sterile males.

More recently, a major Great Lakes concern has been the introduction of exotics through discharge of ballast water. The massive, uncontrolled explosion of the zebra mussel, introduced from Europe to North America in ship's ballast water discharged to Lake St. Clair, probably in 1985, dramatizes this new source of invaders to the Great Lakes (see Box 18.2).

TABLE 18.11

Chronology of wild species deliberately released or accidentally introduced into the Great Lakes aquatic system that successfully propagated

Species	First release/introduction		
	Year	Deliberate or accidental	Lake or drainage
Alewife	1819	accidental	All
Sea lamprey	1829?	accidental	All
Chinook salmon	1873	deliberate	All
Rainbow trout	1876	deliberate	All
Goldfish	1878?	deliberate	All
Common carp	1879?	deliberate	All
Brown trout	1883	deliberate	All
Rainbow smelt	1903	accidental	All
Mosquitofish	1923	deliberate	M,E
Orangespotted sunfish	1929	accidental	E
Coho salmon	1933	deliberate	All
Kokanee	1950	deliberate	H
White perch	1950?	accidental	O,E,H
Pink salmon	1956	accidental	All
Grass carp	1974	deliberate	E
Threespine stickleback	1980	accidental	H,M
Asian Manila clam	1981	accidental	E,M
Bythotrophes cederstoemi	1984	accidental	All
Zebra mussel	1985	accidental	E
Ruffe	1987	accidental	S
Fourspine stickleback	1987	accidental	S

Note: E–Erie; H–Huron; O–Ontario; M–Michigan; S–Superior. Deliberate releases that did not successfully reproduce include American shad, arctic charr, striped bass, arctic grayling, cutthroat trout, etc.; unsuccessful accidental introductions include European flounder and Chinese mitten crab.

Source: Emery (1985). Species introduced after 1985 are from International Joint Commission (1987*a*).

Complex issues in fisheries management

The fishery in the Great Lakes, like agriculture, is increasingly characterized by the replacement of the natural ecosystem by an altered or manipulated one. It is obvious that many of the original fish stocks have been replaced, and that the replacement process is ongoing. Whether this is beneficial for the ecosystem as a whole is unknown, but, as Colborn *et al.* (1990) have pointed out, "to assume that 'what is good for the fishery resource is good for the ecosystem' is an oversimplification."

The state of the Great Lakes fishery and that of the larger Great Lakes aquatic ecosystem are integrally connected. Inevitably, incompatible interests exist, including: (1) recreational versus commercial versus subsistence fishing; (2) hatchery programs in support of the lucrative recreational fishing industry versus moving the system towards a self-sustaining status; and (3) limiting nutrients to protect water quality versus increasing nutrients in support of a bountiful fishery. Although the Great Lakes fishery is currently more robust than it was in the early 1980s, major management efforts will be required to bring together competing interests and to foster a broad appreciation of the aquatic ecosystem as a whole.

BOX 18.2

Zebra mussel: invader of a different stripe

Small but mighty, the zebra mussel is infiltrating the waterways of North America. Native to the Black and Caspian seas, this fingernail-size, yellow-and-brown-striped mollusc can now be found in all of the Great Lakes as well as the St. Lawrence River.

Finding a niche in an already disturbed ecosystem, the prolific mollusc has undergone a population explosion. In western Lake Erie, an ideal warm-water habitat rich in algae (for food) and calcium (for shell growth), densities of 700 000 per cubic metre have been found. In other lakes, the absence of these ideal conditions will limit distribution and growth, and such extreme densities are unlikely.

Under the right (or wrong) conditions, zebra mussels attach to and encrust all hard surfaces, including water intake pipes and rocky, fish spawning shoals. Their effect can be devastating, economically and ecologically. Preliminary research results concerning impacts on fish spawning shoals are more favourable than at first anticipated, but it is still too early to be optimistic.

As they are filter feeders, zebra mussels affect the overall aquatic ecology. They remove phytoplankton from the water, which ultimately affects walleye, trout, bass, and perch and fish-eaters at the top of the food chain. Some waterfowl, such as scaup, have discovered the new abundant food source and delay their migration, feasting on zebra mussels. Unfortunately, there are not enough natural predators, such as diving ducks and some fish, to limit the population growth of the pests. The hope is that the zebra mussel population will collapse to and stabilize at a lower level.

Mussel shells can severely restrict water flow, and already they are impairing municipal water supply, agricultural irrigation, and electrical generating plants. Costs of remedial measures, such as chlorination treatment to kill larvae and relocation and redesign of water intakes to deeper water, may exceed hundreds of millions of dollars.

Even so, the zebra mussel is in the Great Lakes to stay. Treatment of ballast by chemicals or heat and mandatory replacement of ballast (a voluntary regime now exists) are under consideration as means of preventing the introduction of other exotic species.

Changing water levels

Fluctuations in water levels underline the dynamic nature of the Great Lakes basin ecosystem and are a natural phenomenon. At the same time, they present a suite of problems for human communities dependent upon stability and predictability. In 1986, except for Lake Ontario, the Great Lakes reached their highest recorded levels this century. The brimming lakes swallowed shoreline properties and even homes — inciting a major public outcry.

Since the mid-1960s, water "quantity" issues have caused almost as much controversy as water "quality" issues.

Shoreline property owners suffer from high water levels that, in combination with storms, can cause severe shoreline erosion. Low levels hamper recreation, constrain the production of hydroelectric power, and jeopardize commercial shipping. On the other hand, fluctuations are considered beneficial for the environment in general and essential for shoreline ecology in particular, raising the question whether manipulation of water levels is desirable.

Citizens' concerns regarding water quantity fall under three broad but related categories: (1) direct problems caused by changing lake levels; (2) opportunities, real and imagined, for maintaining near-constant levels by structural or other means; and (3) prospects for major diversions of water to and from the lakes, primarily to meet demands outside the basin. In response to these concerns, the U.S. and Canadian governments initiated three major studies (International Joint Commission 1964, 1985, 1986). The last of these was motivated by the extreme high water and flood conditions of 1985 and 1986 and is ongoing. The various studies have included review of a century of observation of levels, flows, and the factors that influence them and have led to the following conclusions (Bruce 1984; Project Management Team 1989):

1. Water levels, flows, and precipitation levels have had relatively minor fluctuations about stable mean values, but those that do occur result in large economic losses, gains, or disruptions.

2. Human interventions to control water levels have relatively minor impacts on fluctuations compared to natural forces. At the local level, storms induce the most dramatic changes. As a result, the cost of measures to control water level fluctuations throughout the lakes would be prohibitive. Unless the connecting rivers are all dredged to greater depths and controlled by dams, such efforts would also be futile. A great many people would object to massive dredging and damming.

3. The Great Lakes are not an infinite resource that can be exploited without constraint. They are sensitive to human activity and, as past experience has shown, confound even well-intended actions by unexpected and undesired side-effects. As a result, future management must be supported by thorough analysis of ecological consequences.

These conclusions regarding water quantity echo those that have emerged from three decades of study of water quality issues now enshrined in the Great Lakes Water Quality Agreement, with its "ecosystem approach" to the management of the Great Lakes. A

TABLE 18.12

General conditions to be expected in the Great Lakes basin from a doubling of carbon dioxide in the Earth's atmosphere

Temperature	• higher — mean annual by 4–5°C, mean winter by 5–6°C, and mean summer by 3–4°C
Precipitation	• up
Evaporation and evapotranspiration	• up significantly
Runoff	• down
Snowpack	• reduced by 50–100%
Snow season	• shortened by 2–4 weeks
Ice cover	• reduced, perhaps gone
Soil moisture	• reduced
Overall net basin supply of water	• reduced by 15–30%
Water levels	• reduced

Source: Colborn *et al.* (1990).

study group of the International Joint Commission put the case succinctly, when, in 1989, it concluded that "measures aimed at affecting system-wide water level fluctuations are probably futile."

Climatic change

Global climatic warming would have a profound effect on the hydrologic regime of the Great Lakes (Table 18.12). This has been confirmed by the Intergovernmental Panel on Climate Change (1990). Changes to the natural system would occur gradually, eventually eliminating current features. Many wetlands would disappear, and forests and other land covers would change, along with the wildlife habitat that they provide. Fish habitats would also be dramatically altered, with climatic warming likely to benefit species that favour warmer waters, such as bass, perch, and sunfish, whereas trout, salmon, lake herring, and lake whitefish would likely suffer (Meisner *et al.* 1988; Regier *et al.* 1989). After a period of adjustment, a particular lake would likely produce more fish for harvest, but of a different combination of species.

Reductions, induced by climatic change, in the natural supply of water to the Great Lakes basin would also have far-reaching effects on human activities: reduced lake levels would limit navigation, despite more ice-free days, as well as the generation of hydroelectric power. Changes in temperature and precipitation would significantly affect agriculture, forestry, and recreation.

Effects of climatic change in neighbouring regions might bring more pressure to increase diversion of water out of the Great Lakes. Even now, increased diversion of Great Lakes water to the water-starved southwestern United States remains a simmering issue. One scheme, the GRAND (Great Recycling and Northern Development) Canal, would see James Bay converted into a freshwater lake and water diverted to the Great Lakes in compensation for water exports to the U.S. Obviously, the ecological and economic implications would be extreme, and both are the subject of ongoing debate and research.

ECOSYSTEM APPROACH TO MANAGING THE GREAT LAKES

The Great Lakes basin ecosystem has long been subjected to human-induced stresses that include overharvesting of renewable resources, physical changes, pollution by a range of conventional and toxic contaminants, and the introduction of exotic species. Table 18.13 lists factors that indicate conditions and trends in the environment.

The 1978 Great Lakes Water Quality Agreement undertook "to restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes basin ecosystem." It stated that ecosystem integrity was indeed paramount, and, further, it recognized that solutions required programs that addressed the linkages between all components of the ecosystem — air, land, water, wild plants and animals, and humans and their activities.

Major challenges remain in implementing the ecosystem approach. The reduction of phosphorus input into lakes Erie and Ontario by the regulation of municipal waste sources has been accomplished, but a broad range of physical, chemical, and biological stresses still need to be reduced. Above all, the ecosystem approach demands that people see themselves as part of the ecosystem rather than the dominators of the natural world.

Quality of life of basin residents

Residents in the basin have enjoyed a relatively high standard of living. Statistics on household facilities and equipment in Ontario provide some indication of the lifestyle of contemporary Great Lakes basin residents: 44% of households have air conditioners; 40% have dishwashers; 62% have video cassette recorders; 80% have automobiles; and 30% have two or more automobiles.

Great Lakes residents continue to experience feedback from the lifestyle choices they have made, in the form of pollution and higher costs for energy, food, housing, and other necessities. As well, warnings not to eat certain Great Lakes fish, beach closures, air pollution advisories, and accidents, such as the St. Clair River spill in 1985, have brought people face-to-face with the consequences of their lifestyle.

Increasingly, it is becoming apparent to residents of the basin that they cannot isolate themselves from the consequences of their own actions, and that they are an integral part of the ecosystem. As a result, people are now demanding change that might have been unthinkable even a decade ago. In a 1989 survey conducted by Goldfarb, Torontonians singled out air pollution as their prime environmental concern, and, surprisingly, 71% favoured shutting down polluting factories, even if it meant people would lose their jobs.

TABLE 18.13

Trends in ecosystem health in the Great Lakes basin

Factor	Response time	Basin limited	Current status/trend
A. Concentration of contaminants in specific media			
1. air quality	days–months	no	uneven progress; conditions periodically unacceptable in major cities
2. surface water quality	months–years	yes	general improvement experienced since the 1970s; exceptions with some contaminants and in some local areas
3. contaminated sediments	decades–centuries	yes	generally stable or improving; some exceptions in local areas
4. groundwater	decades–centuries	yes	degenerating; ill-understood system
B. Wildlife, including fish			
5. body burdens of toxics	intergenerational effects documented	no	improvements in the 1970s; trends now variable and inconsistent
6. population status	years–decades	no	variable
7. habitat	days–centuries	yes	slowed rate of loss and deterioration; many critical areas still threatened
8. species diversity	decades–centuries	no	some species at risk
C. Terrestrial vegetation			
9. health of plant communities	months–decades	yes	little monitored; geography-specific; clearly some concerns
10. species diversity	months–decades	yes	some species threatened
D. Land			
11. agriculture to urban conversion	days–years	yes	continuing loss of high-capability agricultural land, but loss per capita decreasing; limited local but not general problem
12. soil productivity	years–decades	yes	generally stable
13. soil erosion	months–decades	yes	continuing natural erosion; generally stable compared to other parts of North America
14. shoreline erosion	days–years	yes	continuing natural erosion; inappropriate use of vulnerable shorelines continuing
E. Human characteristics			
15. human health	days–generations	no	little indication that the health of adults due to toxic contaminants is being compromised; certain subgroups at elevated risk; growing concern for subtle chronic and intergenerational effects

Source: Colborn *et al.* (1990).

Environment–economy linkages and sustainability

The goal of sustainability demands that the public discussion bring together economic and environmental issues. Attitudes are evolving, though very slowly, as contemporary society begins to recognize that the state of the economy is completely dependent upon the state of the environment. The World Commission on Environment and Development (1987) correctly pointed out: "The environment does not exist as a sphere separate from human actions, ambitions, and needs…. The environment is where we all live."

Three stages in the evolution of the "environmental debate" have been recognized: (1) concern for environmental pollution expressed in a "react and cure" mode; (2) integration of environmental concerns into society's mind through public policy- and decision-making that are more "anticipatory and preventative"; and (3) the struggle of shifting priorities as society begins to recognize the changes in lifestyle that will be required to achieve "sustainability" (MacNeill 1989). Inevitably, economic and cultural restructuring will occur on local and global scales.

The "react and cure" mode applies to the 43 Areas of Concern identified by the International Joint Commission (Fig. 18.13). A combination of environmental abuses, including the dumping of municipal sewage and toxic industrial wastes, have severely degraded these areas. Remediation will require expenditure of vast sums of money and decades of remedial action. Cleanup of all Areas of Concern is projected to cost $12–25 billion. Even this may be an underestimate, as the costs associated with a number of factors have not been included in the estimates (Rapport 1989). These include long- and short-term costs associated with:

- resolving the problem of contaminated bottom sediments, for which there is currently no clear technical solution;
- cleanup associated with ongoing containment in hazardous and solid waste management facilities and operating industrial and municipal facilities;
- reductions of contaminant emissions and discharges;
- cleanup of degraded areas around the Great Lakes and inland lakes and rivers that are not currently on the list of 43 Areas of Concern;
- replacement and maintenance of municipal water handling and treatment infrastructure because of rising environmental standards, age, and population growth;
- restoration and maintenance of habitats of fish and other wildlife, including regulation of protected areas, parks, and recreation; and

- reducing the incidence of accidental spills and discharges (many small spills occur annually and large spills also occur, but less frequently).

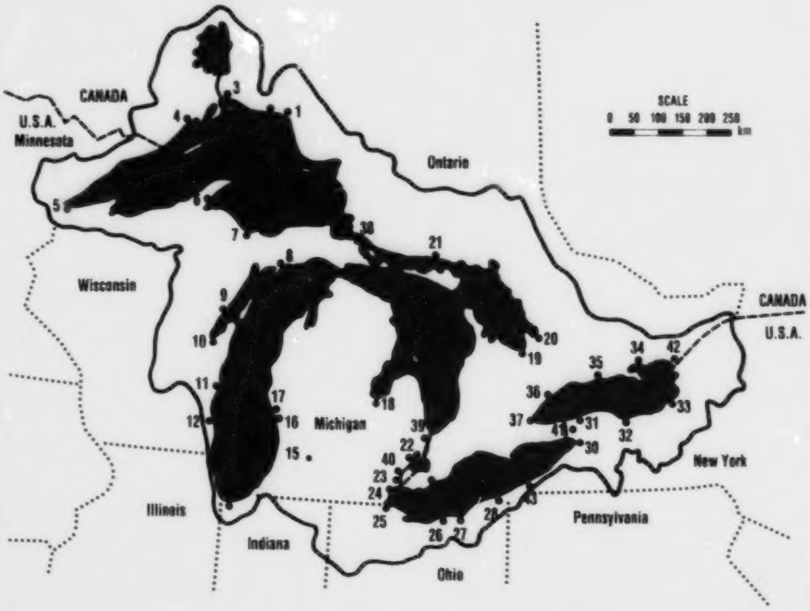
The net result of the early compilation of estimates for rehabilitation of the Areas of Concern, combined with the above hidden costs, leads to the conclusion that costs for reestablishing and maintaining the integrity of the Great Lakes basin ecosystem — the goal of the Great Lakes Water Quality Agreement — will be in the tens of billions of dollars (Colborn *et al.* 1990).

Although the estimate of cleanup cost seems large, the current annual gross domestic product of Ontario combined with that of the eight Great Lakes states is over $1 trillion. Furthermore, if all of this work were undertaken, it would be spread over several decades at least. Past experience has shown that major environmental issues in the Great Lakes — lamprey control, overfishing, phosphate eutrophication, pathogenic pollution, persistent pesticides — have taken at least 25 years to address after an appropriate binational decision was taken, and no issue has yet been fully resolved. However, the real significance of these figures is that they represent in hard economic terms the legacy that has accumulated during two centuries of human activity in the Great Lakes basin. This environmental mortgage has been a direct consequence of society's belief that environmental degradation was an acceptable cost of prosperity and progress. It is now clear, however, that damage to human health and natural resources can no longer be ignored, and that the pattern of environmental degradation must now be reversed.

The weighty cost that current society must bear in paying the debt of degradation has led to policies that are more anticipatory and preventative. This second "step" brings some rather remarkable and encouraging conclusions. Communities redeveloping urban waterfronts around the Great Lakes are taking the lead role in integrating environmental quality with economic activity in a practical way. Toronto, for example, has recognized

FIGURE 18.13

Areas of Concern in the Great Lakes basin



	Area of Concern
	Lake Superior
1	Peninsula Harbour
2	Jackfish Bay
3	Nipigon Bay
4	Thunder Bay
5	St. Louis River / Bay
6	Torch Lake
7	Deer Lake / Carp Creek / Carp River
	Lake Michigan
8	Manistique River
9	Menominee River
10	Fox River / Southern Green Bay
11	Sheboygan Harbor
12	Milwaukee Estuary
13	Waukegan Harbor
14	Grand Calumet / Indiana Harbor
15	Kalamazoo River
16	Muskegon Lake
17	White Lake
	Lake Huron
18	Saginaw River / Bay
19	Collingwood Harbour
20	Penetang Bay to Sturgeon Bay
21	Spanish River
	Lake Erie
22	Clinton River
23	Rouge River
24	River Raisin
25	Maumee River
26	Black River
27	Cuyahoga River
28	Ashtabula River
29	Wheatley Harbour
30	Buffalo River
43	Presque Isle Bay (Erie Harbour)
	Lake Ontario
31	Eighteen Mile Creek
32	Rochester Embayment
33	Oswego River
34	Bay of Quinte
35	Port Hope
36	Toronto Waterfront
37	Hamilton Harbour
	Connecting channels
38	St. Marys River
39	St. Clair River
40	Detroit River
41	Niagara River
42	St. Lawrence River

Source: Colborn *et al.* (1990).

that the waterfront is a great resource, not only for transportation and commerce, but also for an enhanced quality of life for humans and all components of the ecosystem (Royal Commission on the Future of the Toronto Waterfront 1990). The Great Lakes waterfront communities have recognized that development with respect for the ecosystem, far from implying "yet more costs" to society, in fact provides the essential ingredient to renewed economic activity as well as community pride and well-being.

Nonetheless, society's consumption and production habits continue to produce excessive stresses on the environment; this pattern must change if the current deficit of environmental degradation is to be brought under control and sustainability achieved. Analysis of human activities in terms of the stress–response model in the Great Lakes system has effectively demonstrated this conclusion. This shift in habits must be driven by a simultaneous shift in values, and it is this third part of the evolution of the environmental debate that society is just now embarking upon.

There are, in fact, remarkable indications that a turning point in attitude has been achieved, even if little practical progress has been made along the path. In fall 1989, over 800 residents of communities in the Great Lakes basin attended the International Joint Commission's Fifth Biennial Meeting on Great Lakes Water Quality. They urged the Commission to speak forcefully to the U.S. and Canadian governments to stop the ongoing degradation and to adopt policies that put emphasis on anticipation and prevention. This event reflects a shift in values not evident even a few short years ago and is cause for optimism. Furthermore, in many communities, citizens have been active in setting goals for Remedial Action Plans, or RAPs (see Box 18.3), which are the first practical test of the ecosystem approach.

BOX 18.3

Remedial Action Plans, or RAPs: a practical test of the ecosystem approach

In spring, the levels of ammonia are so high in Hamilton Harbour that they are toxic to fish. Ammonia is discharged into the enclosed harbour basin from sewage treatment plants and, to a lesser extent, industry. Ammonia is but one reason that Hamilton Harbour has been designated as an Area of Concern. It is also a cause of the low oxygen conditions in the harbour in summer.

There are 43 Areas of Concern around the Great Lakes (see Fig. 18.13). They are environmental "hot spots" where longstanding problems create an impairment to "beneficial uses" of the water, including its uses for drinking, swimming, and supporting healthy aquatic life. Remedial Action Plans (RAPs) are being developed to clean up each of these areas. RAPs are viewed as an ideal opportunity, on a broad and practical scale, to implement the ecosystem approach to complete environmental restoration in the Great Lakes basin. They are being developed in a way that integrates a wide variety of scientific and technical disciplines, agencies, and community interests. Agencies work with the community to define the environmental problem and its causes and then, at the second stage, collectively develop goals and propose cleanup measures to implementors from all sectors.

The Hamilton Harbour RAP is considered exemplary. Its "stakeholder" group represents agencies at three or four levels of government, private citizens' organizations including environmental groups, elected representatives, and industries — each in some way responsible for, or users of, Hamilton Harbour water.

Buoyed by the documented success of measures to correct water quality problems over the past 20 years, and supported by the public for the final stages of cleanup under the RAP program, the basis will be laid through these collective efforts for the restoration and maintenance of the centrepiece of the watershed and its surrounding communities.

Source: Cole-Misch *et al.* (1990).

CONCLUSIONS

Likely, the Great Lakes basin ecosystem came closest to catastrophe in the late 1960s and early 1970s. From many perspectives, conditions have since improved. A major binational success was achieved when nutrient levels were significantly reduced. Concentrations of toxic contaminants also have been reduced, but it is now apparent that the ongoing reduction has tapered off and reached a plateau at levels that will continue to cause significant ecosystem degradation.

Despite the gains of the last two decades, the Great Lakes ecosystem is still threatened. Conditions for fish and other wildlife remain degraded, and human health as well as ecosystem well-being are at risk. Many bays, harbours, and channels remain severely degraded, and assessment of the cost of rehabilitating these degraded areas has brought to light a significant environmental "mortgage" of tens of billions of dollars. Thus, the overall assessment of the Great Lakes state of the environment leaves one with: (1) a sense of caution despite some encouraging signals; (2) ongoing concern for current ecosystem conditions; and (3) a sense of urgency to both clean up existing Areas of Concern and prevent new ones.

Future economic decision-making must take into account the limits and interconnected nature of the surrounding environment, if the basin is to move toward a more sustainable state — sustainable in terms of ecological, social, economic, and health well-being. There is a need for more anticipatory approaches, which place emphasis on prevention rather than cure. A number of communities are putting this theory into practice in upgrading waterfront areas. However, consumers, in making everyday decisions regarding everything from automobile purchases, gardening practices, and energy uses, must take into account their influence on the environment. A spirit of cooperation and commitment between business, municipalities, and environmentalists, as evidenced by the Remedial Action Plan process, must also be fostered in order that workable solutions can be found and implemented. Such a shift in values is emerging among the residents of the basin and is cause for optimism.

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SERGE CÔTÉ, L'IMAGIER ENR.

HIGHLIGHTS

The St. Lawrence's freshwater, brackish water, and saltwater ecosystems contain habitats that are essential to the survival of communities of flora and fauna. However, the deterioration of water quality and river habitats has had harmful effects: some 30 species of fauna and 183 plant species within the St. Lawrence corridor face extinction.

■

The St. Lawrence valley has nearly 5 million inhabitants, 4.3 million of them Quebeckers. Almost half of Quebec takes its drinking water from the river, but it will not be until 1994 that 85% of the population will be served by sewage systems connected to purification plants.

■

Quebec's most industrialized regions are located along the St. Lawrence River. Industries take their water supply from the river and dump their effluent into it. To this is added untreated wastewater from municipalities and agricultural seepage and runoff.

■

Commercial shipping is of great economic importance; however, potential spills threaten aquatic ecosystems. Backfilling and dredging of the river alter aquatic habitats.

■

Tourism in Quebec also generates major economic returns. Most tourist information centres, historic sites, and recreational activities are concentrated in the St. Lawrence valley. Close to cities, microbial pollution of the river, especially near sources of untreated wastewater, jeopardizes water-based recreation.

■

Federal, provincial, and municipal pollution control initiatives will have a positive effect on the quality of the river's waters, but certain toxins (PCBs, PAHs) will continue to accumulate in its sediments or the food chain.

■

Considerable headway has been made in reducing pulp and paper and refinery waste, but much remains to be done; the metallurgical, inorganic chemical, and surface finishing sectors are not yet governed by regulations.

■

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> **“In times past, for thousands upon thousands of years, this unnamed river flowed towards the Ocean under the watchful eye of God. From its source in a great nameless lake, it wound its way around rocky islets and green islands. At times, it swelled like a boa devouring its prey, and in these stretches it hugged its gently sloping bed and moved through a silence caressed by rustling leaves or grazed by the cry of a bird… then suddenly, shattering the peace of the woods, it erupted into a raging whirlpool, waves rushing into each other, boiling expanses of foam dragged down by other cataracts. At last, the shores loosened their grip, and grand and proud, the river known only to God went out to meet the tides and the seaweeds, towards a gulf as vast as the sea, in which it met both its triumph and its death. [translation]”**
>
> — Choquette (1972)

INTRODUCTION

For generations, millions of Quebeckers have had a close relationship with the St. Lawrence River. This is because of the waterway's strategic importance as well as the boundless wealth that it harbours. Today, however, this privileged link is threatened because the fact that the St. Lawrence is first and foremost a life-supporting environment has been ignored for too long.

The widespread North American view that natural resources are inexhaustible led to abuse of this valuable asset. Fortunately, this attitude is becoming increasingly rare, and governments, the public, and industry are all beginning to see things differently.

Despite its extraordinary potential, the St. Lawrence cannot be exploited indefinitely. Here, as elsewhere, people are finally realizing that respect for nature must shape the relationship that human beings have with the environment. The following pages provide an indication of how concerted action can rehabilitate the river.

THE ST. LAWRENCE FROM ALL ANGLES

The St. Lawrence has been instrumental in shaping Canada's history. The Amerindians, who called it "the moving trail," depended on it for transportation and subsistence. European colonists used it to reach the continent's heartland or settled along its shores, where they did so well that the history of New France is tied closely to that of the St. Lawrence.

For centuries, the St. Lawrence was the focus of settlement and figured prominently in the development of a bustling economy. Some of Canada's largest cities sprang up on its shores: more than 80% of the population of Quebec is concentrated in a narrow corridor on either side of the river. Many industrial plants, including some of the country's biggest, were also built along its shores.

The St. Lawrence became the world's largest inland navigable waterway in 1959 when the St. Lawrence Seaway was opened. The seaway provides access to Lake Superior, 3 750 km from the Atlantic Ocean. The river plays a key role in transporting cargo of all types, with more than 1.2 billion tonnes moving through it between 1959 and 1989 (Scott *et al.* 1989). The Mississippi River is the only waterway in North America that carries a greater volume (Morissette *et al.* 1985).

The St. Lawrence is also a holiday destination of long standing. In the 19th century, entire regions opened their doors to large numbers of summer tourists. In Kamouraska, Notre-Dame-du-Portage, Cacouna, and La Malbaie, the seasonal influx of city dwellers bolstered the development of a tourist industry that is important to area residents. In sum, the St. Lawrence is a landmark, a point of reference that has a special place in the hearts of many Quebeckers.

Source and size

The St. Lawrence River issues from the Great Lakes, which supply most of its flow. Its flow rate fluctuates around 7 300 m^3/s where it leaves Lake Ontario, and water from the Great Lakes still constitutes an estimated 54% of its flow as far downriver as Tadoussac.

The river proper, the estuary, and the gulf drain some 673 000 km^2 of land (Scott *et al.* 1989). Including the area drained by the Great Lakes, which are virtually inseparable from the St. Lawrence system, the surface area of its drainage basin rises to 1 183 324 km^2 (Germain and Janson 1984), ranking the St. Lawrence second among Canadian waterways, after the Mackenzie River. The St. Lawrence tops the list of Canadian waterways, however, for mean discharge.

The St. Lawrence stretches over more than 1 500 km and is bordered by 4 200 km of shoreline (LAPEL Inc. 1989).

Its configuration varies greatly from a narrow channel to a vast gulf, via rapids and areas where it widens naturally (lakes Saint-François, Saint-Louis, and Saint-Pierre and the La Prairie basin). From barely 1 km just upriver from Quebec City, the St. Lawrence widens to 70 km at Baie-Comeau.

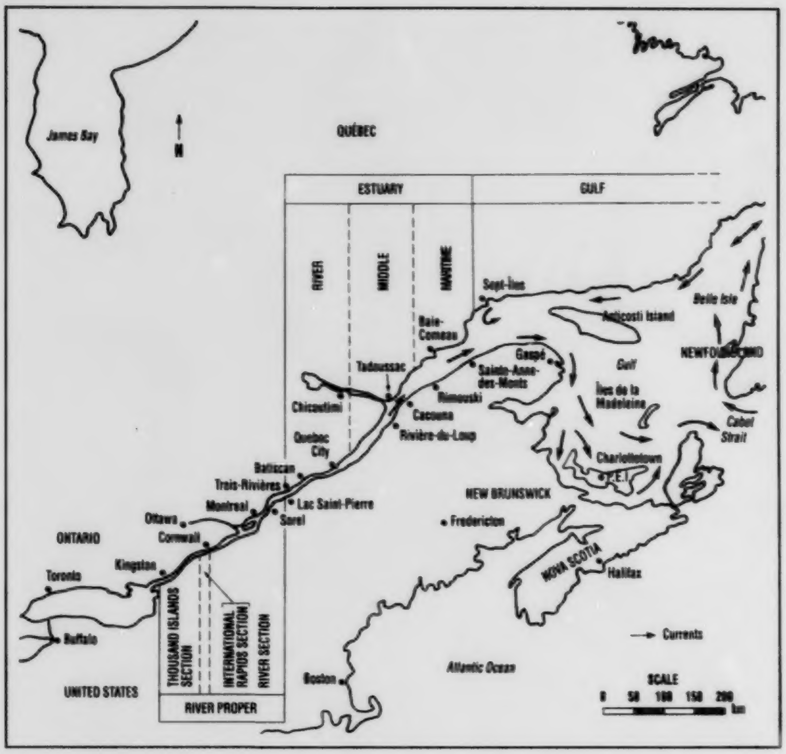
The St. Lawrence's hydrographic basin includes hundreds of watercourses. In order of the surface area they drain, the main rivers to the north of the St. Lawrence are the Ottawa (146 000 km^2), the Saguenay (88 000 km^2), the Manicouagan (45 900 km^2), and the Saint-Maurice (43 200 km^2); and to the south, the Richelieu (23 700 km^2), the Saint-François (10 200 km^2), and the Chaudière (6 690 km^2) (Landry and Mercier 1984).

Hydrodynamic profile

The hydrologic properties of the St. Lawrence vary by river segment. The movement of the water is dictated by a combination of factors, including riverbed contours, water depth, freshwater supply, currents, and tides (Fig. 19.1).

FIGURE 19.1

Division of the St. Lawrence River into the river proper, the estuary, and the gulf


James Bay
N
QUÉBEC
ESTUARY
GULF
RIVER
MIDDLE
MARITIME
Sept-Îles
Anticosti Island
Belle Isle
Baie-Comeau
Gaspé
Tadoussac
Sainte-Anne-des-Monts
Gulf
NEWFOUNDLAND
Îles de la Madeleine
Rimouski
Chicoutimi
Cacouna
Cabot Strait
Quebec City
Rivière-du-Loup
Charlottetown
P.E.I.
Batiscan
Trois-Rivières
NEW BRUNSWICK
Montreal
Lac Saint-Pierre
Ottawa
Sorel
Fredericton
ONTARIO
Cornwall
Kingston
NOVA SCOTIA
Toronto
Halifax
Buffalo
THOUSAND ISLANDS SECTION
INTERNATIONAL RAPIDS SECTION
RIVER SECTION
Currents
Atlantic Ocean
SCALE
0 50 100 150 200 km
Boston
UNITED STATES
RIVER PROPER

The river proper, the portion unaffected by tides, is divided into three sections: the Thousand Islands section, the International Rapids section, and a final stretch that extends to Lake Saint-Pierre. This main stem is marked by a significant vertical drop between Lake Ontario and Montreal: 72 m over a distance of 300 km. The river proper has been greatly altered by dams and dredging aimed at maintaining a depth of 10.7 m in the ship channel (Groupe d'initiatives et de recherches appliquées au milieu 1989). It is characterized by slow-flowing waters and stretches where the river widens naturally, forming lakes that rarely exceed 6 m in depth. These characteristics promote sedimentation (Ministère de l'Environnement du Québec 1988*b*).

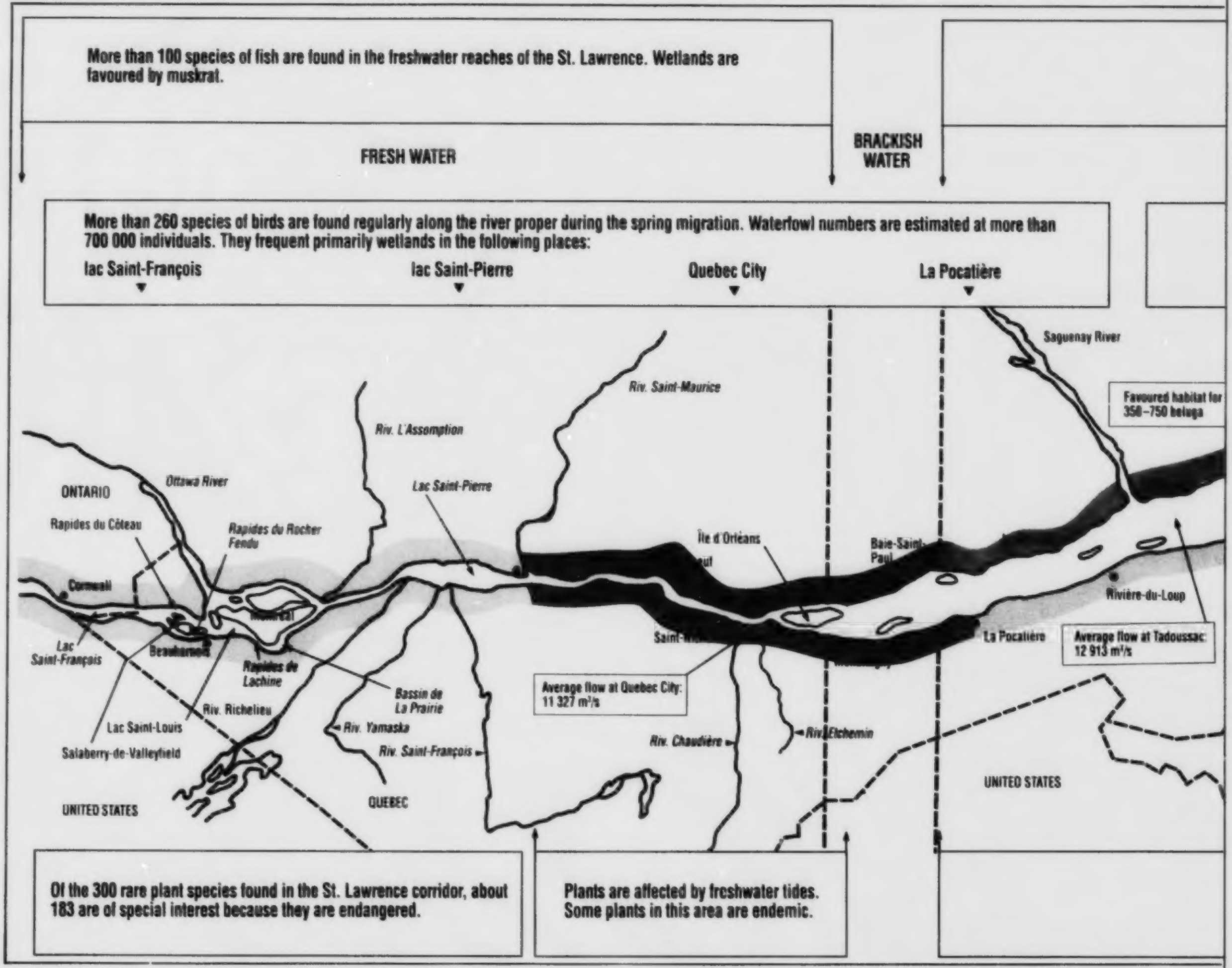
Contrary to what one might think, the waters of the river proper are not homogeneous: they are made up of adjoining masses, principally "green waters" from the Great Lakes and "brown waters" from the Ottawa River and the north shore tributaries (Verrette 1990). Green waters are characterized by low turbidity, high mineral content, and low nutrient content. Brown waters from tributaries flowing over the bedrock of the Canadian Shield are marked by high turbidity and low mineral content (Désilets and Langlois 1989). Because of the hydrodynamic properties of the river, these masses of water flow side by side along the shore of their origin and mix completely only in the Portneuf region, upriver from Quebec City.

The estuary is divided into three sections: the river estuary, the middle estuary, and the maritime estuary. The river estuary differs from the river proper in that it is affected by tides. From Batiscan onwards, the current reverses with the rising tides, which affects water quality, especially in urban areas. The bathymetric properties of the river estuary are similar to those of the river proper, except for a 40-m-deep rift close to Beaupré, downriver from Quebec City (Roche Ltée 1983). The current is concentrated in the deep channel in mid-river, thereby reducing the flow rate near the shores and decreasing the St. Lawrence's capacity to dilute wastewater (Houde and Dumas-Rousseau 1977). From Cornwall to Quebec City, the mean discharge increases from 7 362 to 11 327 m^3/s (Germain and Langlois 1989).

The depth of the water in the middle and maritime estuaries varies from approximately 100 m downriver from Orleans Island (where the middle

FIGURE 19.2

Biophysical features of the St. Lawrence River



More than 100 species of fish are found in the freshwater reaches of the St. Lawrence. Wetlands are favoured by muskrat.

More than 260 species of birds are found regularly along the river proper during the spring migration. Waterfowl numbers are estimated at more than 700 000 individuals. They frequent primarily wetlands in the following places:

Of the 300 rare plant species found in the St. Lawrence corridor, about 183 are of special interest because they are endangered.

Plants are affected by freshwater tides. Some plants in this area are endemic.

Favoured habitat for 350–750 beluga

Average flow at Quebec City: 11 327 m³/s

Average flow at Tadoussac: 12 913 m³/s

FRESH WATER
BRACKISH WATER
lac Saint-François
lac Saint-Pierre
Quebec City
La Pocatière
ONTARIO
Ottawa River
Rapides du Côteau
Rapides du Rocher Fendu
Cornwall
Lac Saint-François
Beauharnois
Rapides de Lachine
Lac Saint-Louis
Salaberry-de-Valleyfield
Riv. Richelieu
Bassin de La Prairie
Riv. L'Assomption
Lac Saint-Pierre
Riv. Yamaska
Riv. Saint-François
QUEBEC
UNITED STATES
Riv. Saint-Maurice
Île d'Orléans
Baie-Saint-Paul
Riv. Chaudière
Riv. Etchemin
Saguenay River
Rivière-du-Loup
La Pocatière
UNITED STATES

estuary begins) to more than 300 m at the mouth of the Saguenay (LAPEL Inc. 1989). The waters of the middle estuary are brackish as far as Baie-Saint-Paul, after which salt water predominates (Fig. 19.2). The maritime estuary, which begins around Cacouna, is marked by vertical stratification of the water: depending on the season, two or three superimposed layers, each with distinct thermal and saline conditions, can be observed. Salt water from the ocean is colder and heavier than fresh water from the river. Thus, it remains on the bottom, causing the greater salinity of the lower layer.

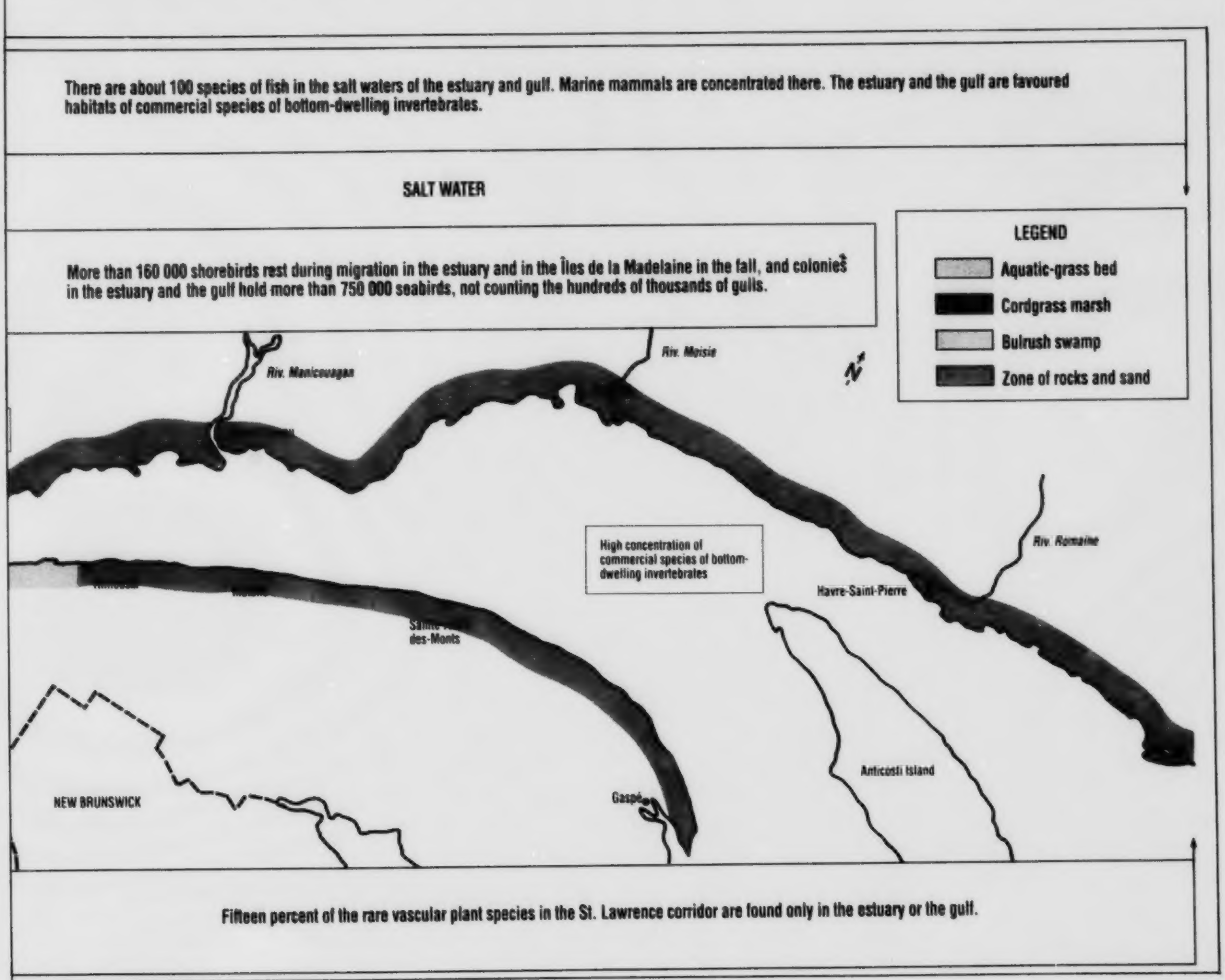
In the gulf, depths may reach 400 m, and, as in the estuary, the water is stratified in three layers, with the lowest layer increasing in size closer to the ocean. The St. Lawrence is 90 km wide at Sept-Îles and continues to broaden from that point onward. The Strait of Belle Isle to the east and Cabot Strait to the south separate the Gulf of St. Lawrence from the Atlantic Ocean.

A precarious future

The waters of the Great Lakes flow into the St. Lawrence River. Many Quebec watercourses also pour into it after crossing densely populated agricultural and industrial regions. Consequently, the St. Lawrence is subject to pressures from its source to its mouth.

Historically, the river and its tributaries were convenient natural dump sites. Their self-purifying properties were sufficient when populations were relatively small; but, with rapid industrialization, more and more people settled in the cities that sprang up along the St. Lawrence, and the amount of waste in the river also increased. Municipalities and industries have

FIGURE 19.2 (CONT'D)



There are about 100 species of fish in the salt waters of the estuary and gulf. Marine mammals are concentrated there. The estuary and the gulf are favoured habitats of commercial species of bottom-dwelling invertebrates.

SALT WATER

More than 160 000 shorebirds rest during migration in the estuary and in the Îles de la Madelaine in the fall, and colonies in the estuary and the gulf hold more than 750 000 seabirds, not counting the hundreds of thousands of gulls.

High concentration of commercial species of bottom-dwelling invertebrates

Fifteen percent of the rare vascular plant species in the St. Lawrence corridor are found only in the estuary or the gulf.

Source: Ministère de l'Environnement du Québec (1988*a*); Gratton and Dubreuil (1990).

continued to draw water from the St. Lawrence, while blithely dumping their waste into it.

It was years before people realized that these water reserves were threatened. Although drinking water treatment processes were initially developed around 1850, the first piece of legislation to acknowledge the rights of all Quebeckers to a quality environment (Quebec's *Environmental Quality Act*) was adopted only in 1972. In 1978, the Quebec government reached a milestone by launching a vast wastewater treatment program at a cost of $6 billion. Results of this program are already noticeable. Since the main sewer began operation in the Montreal Urban Community, water quality has improved in the northern part of Lake Saint-Louis (Montreal Urban Community 1989).

This progressive improvement in water quality, at least in some sectors of the river, is not unrelated to the renewed popularity of water sports. New marinas have been built and existing ones expanded, and a growing number of windsurfers manoeuvre their coloured sails across the surface of the river. Thus, the St. Lawrence, polluted as it is, is nevertheless greatly appreciated by the residents of its shores and tourists alike.

A FRAGILE ENVIRONMENT

The natural wealth of the river

Its ecosystems

The St. Lawrence's ecosystems are particularly rich and diversified; to date, those associated with lakes, rapids, and wetlands are best understood.

The lacustrine zone is located in the freshwater portion of the river. It comprises lakes Saint-François, Saint-

Louis, and Saint-Pierre and the La Prairie basin (Fig. 19.2). These bodies of water are prime environments for aquatic plants and also contain choice habitats for fish and birds because their oxygenated, nutrient-rich waters are shallow and clear and the current is weak. Lake Saint-Louis, with 77 species of fish and 540 species of aquatic plants, is one of Quebec's richest natural environments (Comité d'étude sur le fleuve Saint-Laurent 1978).

The St. Lawrence's lacustrine ecosystems are more or less permanent depositories for toxic inorganic (heavy metals) and organic (e.g., PCBs, hydrocarbons, pesticides) substances. The massive influx of organic matter and fertilizing substances (e.g., the nitrogen and phosphorus contained in municipal, agricultural, and industrial wastewaters) can cause excessive plant growth. This, in turn, alters the composition of plant and animal communities, so that populations of a few species soar, to the detriment of diversity.

Also located in the St. Lawrence proper are the rapids. In Quebec, they are concentrated in the Montreal region. The main ones are the Lachine, Rocher Fendu (Beauharnois), and Côteau (Valleyfield) rapids. These stretches of white water revitalize the watercourse: their turbulence introduces oxygen, which is essential for aquatic life, providing choice habitats for the reproduction of walleye, trout, and many other species of fish. Rapids are the areas least likely to ice over: downriver are rare expanses of open water used by wintering ducks and gulls.

Wetlands are zones of contact between land and water. Marked by lush vegetation of great diversity, they contain essential wildlife habitats. Here, many insects, molluscs, fish, amphibians, reptiles, birds, and mammals find food and shelter. Wetlands slow down shoreline erosion and contribute to the natural water purification process by filtering out organic matter and sediments, with which pollutants tend to associate.

The St. Lawrence corridor includes many types of wetlands, the main three being aquatic-grass bed, bulrush swamps, and cordgrass (*Spartina* sp.) marshes (Fig. 19.2). The aquatic-grass bed is dominated by underwater or floating species, whereas the bulrush swamps and cordgrass marshes are composed of homogeneous groups of plants emerging from the water at low tide.

Types of wetlands vary with the conditions that exist in the various river segments. The tideless freshwater zone hosts mainly aquatic-grass beds, which occupy considerable areas in lakes Saint-François, Saint-Louis, and Saint-Pierre. In tidal freshwater zones and in brackish waters, bulrush swamps predominate (Fig. 19.2). Although the rock-and-sand shores in the saltwater zone are less conducive to the formation of marshlands, cordgrass marshes are found on the river's south shore between La Pocatière and Rimouski. Saltwater grasslands predominate on favourable sites.

The estimated total surface area of the wetlands is 79 700 ha, of which 63 000 ha (79%) are situated in the river and 16 700 ha (21%) are found in the estuary and the gulf. Aquatic-grass beds make up almost half of the wetlands in the river proper (Gratton and Dubreuil 1990).

Vegetation

The diversity of the St. Lawrence's vegetation is influenced by the many physiographic, hydrographic, and geological landforms through which the river flows. A recent study divided the river into eight biogeographic zones based on physical, chemical, and biological features (Ghanimé *et al.* 1990). Along the shores of the river — including the freshwater segment, the saltwater transition area, and the maritime portion — are 10 vegetation zones. The boundaries of these vegetation zones are determined by factors such as climate, current speed, salinity, and existence and strength of tides.

Some 1300 species of vascular plants — half of the 2 600 species found in Quebec — grow within the St. Lawrence corridor (1 km on both sides of the river) (Gratton and Dubreuil 1990). According to the most recent inventory (Bouchard *et al.* 1983), Quebec is home to 450 species of rare vascular plants. These species are of particular interest because they also indicate the scarcity of their required habitat. More than 300 of them grow in the St. Lawrence corridor; about 183 are of prime importance because they may be threatened with extinction (Gratton and Dubreuil 1990). Close to 50% of these important rare species are found in the northern limits of their range, whereas 11% (20 species) are restricted exclusively to the St. Lawrence estuary and Gulf of St. Lawrence (endemic plants).

Fauna

The St. Lawrence is dotted with spawning grounds, breeding sanctuaries, staging areas, feeding grounds, and wintering areas for many species of fish, birds, mammals, and invertebrates. Most of these are native, although some nonnative species have been introduced by people, notably the rainbow trout, carp, and brown trout.

The river's invertebrates include many different species, but the best known are the bottom-living invertebrates. Their distribution is based on various abiotic factors (e.g., sediment texture, water depth, speed of currents, water quality), biotic factors (e.g., the presence of vegetation), and species-specific characteristics (e.g., food, habitat, reproduction). The freshwater invertebrates comprise mainly molluscs (gastropods, bivalves), crustaceans (gammarids, crayfish), and insect larvae. They are more common in waters with a very weak current — for example, in lakes. The saltwater invertebrates are the best known, and many are exploited commercially (e.g., lobster, crab, scallop, oyster); others are particularly interesting for observation (e.g., starfish, sea urchin). Invertebrates are the basis of the food chain, which includes fish, birds, marine mammals, and humans.

Quebec is home to 87 species of freshwater fish, 18 diadromous species (fish whose life cycle is divided between fresh water and salt water), and 80 saltwater species (Ouellette 1990). Most of these 185 species can be found in the waters of the St. Lawrence. Commercial and recreational fishing are major activities in Quebec and all along the St. Lawrence.

The populations of various species have declined as a result of changes to habitats and deterioration of the natural environment resulting mainly from construction work and maintenance dredging of the ship channel (Robitaille *et al.* 1988; Dryade Ltée 1989). In the late 1960s, Atlantic sturgeon, lake whitefish, and rainbow smelt virtually disappeared from commercial fishing catches in inland tidal waters, and striped bass completely disappeared from the St. Lawrence (Robitaille *et al.* 1988). Lake whitefish seem to be regenerating, but rainbow smelt and Atlantic tomcod stocks continue to diminish. Despite the renewed presence of Atlantic sturgeon in commercial catches in the estuary since the late 1970s, this species is still in the regeneration stage and has experienced highly variable annual growth (Therrien *et al.* 1988).

The St. Lawrence also boasts a diversity of bird species: more than 260 regularly frequent the river, and 115 are closely associated with it (Ghanimé *et al.* 1990). During spring migration, up to 700 000 individuals of various species of waterfowl have been counted; during fall migration, at least 160 000 shorebirds (sandpipers, plovers, yellowlegs, godwits, and curlews) stop there on their flight from the Arctic (Maisonneuve *et al.* 1990). Large seabird colonies are found in the maritime estuary and gulf. The most recent inventories revealed more than 115 000 alcids (Razorbills, murres, puffins, and guillemots), 635 000 Northern Gannets, 27 000 cormorants, and hundreds of thousands of gulls (P. Brousseau, Environment Canada, personal communication).

The dynamics of bird populations vary by species and by river segment. For example, the population of Double-crested Cormorants in the estuary apparently increased 54% between 1963 and 1980 (DesGranges *et al.* 1984), a trend due, in part, to enhanced protection of breeding colonies and a change in attitude towards these birds, which were long considered pests by fishers. The increase in organic waste close to urban centres, wharves, and fishing ports has resulted in a marked upswing in the gull population along the St. Lawrence (Chapdelaine and Bourget 1981). Despite the rise in some bird populations, the survival of other species native to the river is threatened — for example, the Piping Plover and Caspian Tern (Robert 1989).

Because of its high productivity, the St. Lawrence is able to support numerous species of semiaquatic and marine mammals. The muskrat is the most characteristic semiaquatic mammal. The marine mammals are divided into two main groups — pinnipeds (seals) and cetaceans (whales) — concentrated in the salt waters of the estuary and the gulf. These waters are home to five species of seal and 18 species of whale, including the beluga and the humpback. The populations of these two species range from 350 to 750 and from 2 000 to 4 000 individuals, respectively (Ministère de l'Environnement du Québec 1988*b*; Department of Fisheries and Oceans and Environment Canada 1989). At one time, the St. Lawrence beluga population was practically wiped out by overharvesting; it is now threatened by pollution, among other ills (see Box 19.1).

The human presence

Population growth

The St. Lawrence valley has some 5 million inhabitants, 4.3 million of them Quebeckers. They are concentrated mainly in the major urban centres (Fig. 19.3), and almost half take their drinking water from the river (Scott *et al.* 1989).

Linking the centre of the continent and the ocean, the St. Lawrence has always had a strong influence on the geographic distribution of the population. The river was sacred to the native communities living on its shores. Before the arrival of Europeans, the 10 000 inhabitants of Hochelaga (Montreal) and Stadacona (Quebec City) lived off the bounty of the river. Urbanization and agriculture forced most of the native communities inland, but some 13 communities containing 40 000 individuals still occupy 60 700 ha along the river (Scott *et al.* 1989).

Industrial activities

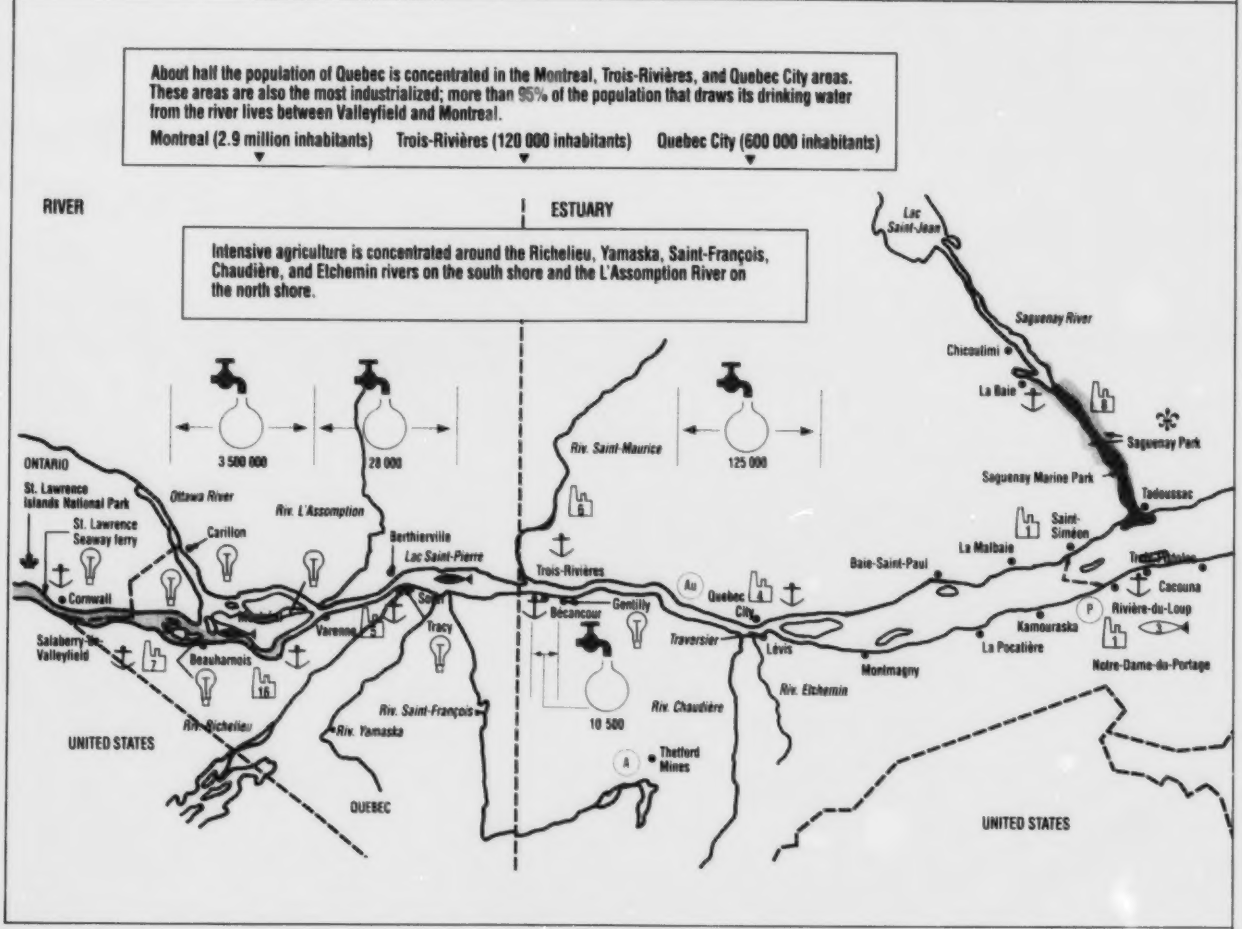
The St. Lawrence has long been an important factor in industrial development. Its corridor crosses some of the continent's most industrialized regions: close to three-quarters of Quebec's industries are concentrated between the Ontario border and Sorel. Their activities are highly diversified — mainly processing and production in the secondary sector.

Quebec's most important industrial region is Montreal, dominated by the textile, metallurgical, chemical manufacturing, and petroleum industries. The Quebec City region ranks second (food and manufacturing industries, pulp and paper, and transportation equipment), followed by the Trois-Rivières region (pulp and paper, clothing, and secondary metallurgical industry). Valleyfield, Beauharnois, Candiac, Berthierville, Sorel, and Bécancour are the remaining principal industrial areas. Tributaries such as the Saguenay, Yamaska, Saint-Maurice, and Ottawa rivers drain other highly industrialized regions.

These industries get their water from the St. Lawrence and its tributaries (see Box 19.2). In that the effectiveness of certain industrial processes depends on the quality of the water used and that this quality is seriously threatened by industrial effluents, industries suffer the consequences of their own pollution.

FIGURE 19.3

Socioeconomic characteristics of the St. Lawrence River



About half the population of Quebec is concentrated in the Montreal, Trois-Rivières, and Quebec City areas. These areas are also the most industrialized; more than 95% of the population that draws its drinking water from the river lives between Valleyfield and Montreal.

Montreal (2.9 million inhabitants) Trois-Rivières (120 000 inhabitants) Quebec City (600 000 inhabitants)

Intensive agriculture is concentrated around the Richelieu, Yamaska, Saint-François, Chaudière, and Etchemin rivers on the south shore and the L'Assomption River on the north shore.

RIVER
ESTUARY
3 500 000
28 000
125 000
10 500
ONTARIO
St. Lawrence Islands National Park
St. Lawrence Seaway ferry
Cornwall
Ottawa River
Carillon
Riv. L'Assomption
Berthierville
Lac Saint-Pierre
Salaberry-de-Valleyfield
7
Beauharnois
16
Varennes
5
Sorel
Tracy
Riv. Richelieu
Riv. Saint-François
Riv. Yamaska
UNITED STATES
QUEBEC
Riv. Saint-Maurice
6
Trois-Rivières
Bécancour
Gentilly
Au
Quebec City
4
Traversier
Lévis
Riv. Chaudière
Riv. Etchemin
A
Thetford Mines
Lac Saint-Jean
Saguenay River
Chicoutimi
La Baie
8
Saguenay Park
Saguenay Marine Park
Tadoussac
Saint-Siméon
1
La Malbaie
Baie-Saint-Paul
Montmagny
La Pocatière
Kamouraska
Trois-Pistoles
Cacouna
P
Rivière-du-Loup
3
1
Notre-Dame-du-Portage
UNITED STATES

Commercial fishing

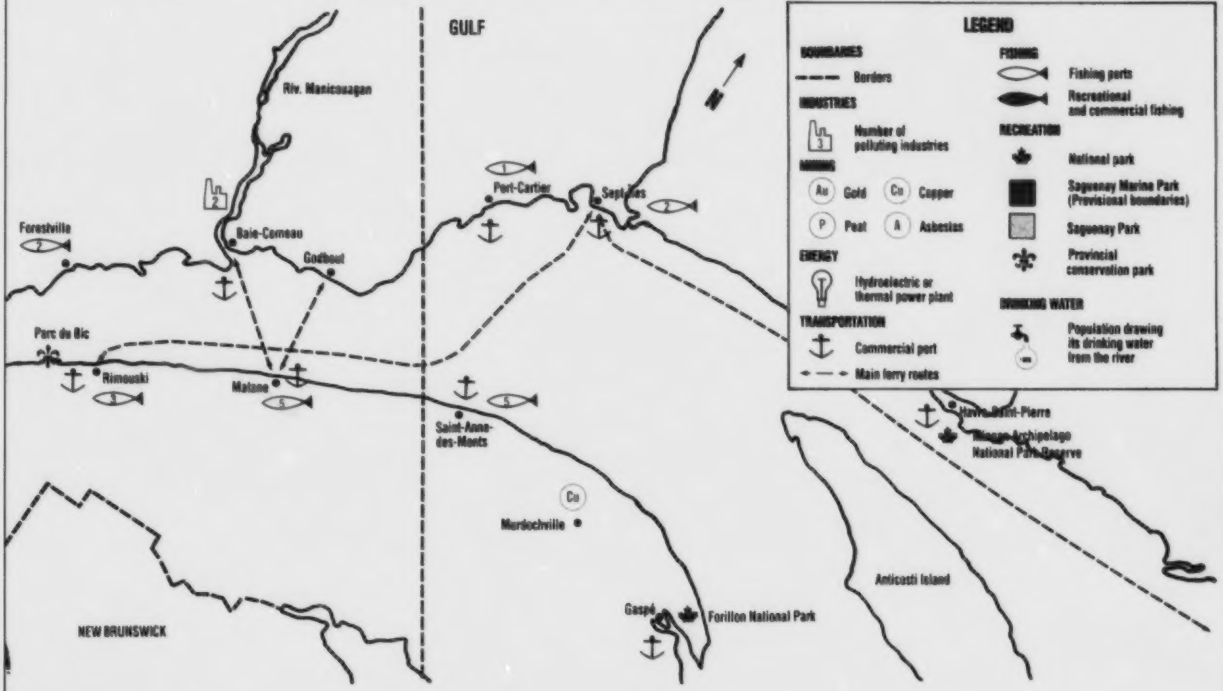
Commercial fishing in the St. Lawrence accounts for barely 0.1% of Quebec's gross domestic product (Department of Fisheries and Oceans 1985). However, it is the key economic activity of many communities in the eastern part of the province. In 1988, the Quebec fishing industry provided close to 12 500 jobs. In 1990, catches represented $72 million, and the value of products processed in Quebec's 125 plants totalled $196 million (Department of Fisheries and Oceans 1991).

Commercial fishing in the river proper was vital to the development of eastern Canada but has declined greatly in the 20th century. Outside Lake Saint-Pierre, where perch, catfish, lake sturgeon, and American eel are still fished, abundant catches are just a fond memory (Robitaille *et al.* 1988). The $2.3 million commercial catch taken from the St. Lawrence proper in 1988 represented a mere 2% of revenues from fishing in Quebec (Department of Fisheries and Oceans 1989). A total of 92% of commercial catches in the river-proper section come from the Mauricie area (Mailhot 1990).

The main commercial fishing activities are concentrated in the gulf and the estuary and account for almost all of the province's revenues from fishing. From 1984 to 1988, commercial catches in Quebec fluctuated between 80 000 and 100 000 t (approximately 7% of the total for eastern Canada). The stability of the catch, however, masks the fact that in recent decades there have been major declines in stocks that do not readily recover. The survival of the fishing industry depends on rational, regulated exploitation of fish stocks (see Box 19.3).

FIGURE 19.3 (CONT'D)

The most important commercial fishing activities are concentrated in the estuary and gulf. Fish catches are worth more than $70 million annually. Cod, red fish (haddock), herring, shrimp, and snow crab are among the most important commercial species.


GULF
N
Riv. Manicouagan
Forestville
Baie-Comeau
Godbout
Port-Cartier
Sept-Îles
Parc du Bic
Rimouski
Matane
Saint-Anne-des-Monts
Murdochville
Havre-Saint-Pierre
Mingan Archipelago National Park Reserve
Anticosti Island
Gaspé
Forillon National Park
NEW BRUNSWICK
LEGEND
BOUNDARIES
Borders
INDUSTRIES
Number of polluting industries
MINING
Gold
Copper
Peat
Asbestos
ENERGY
Hydroelectric or thermal power plant
TRANSPORTATION
Commercial port
Main ferry routes
FISHING
Fishing ports
Recreational and commercial fishing
RECREATION
National park
Saguenay Marine Park (Provisional boundaries)
Saguenay Park
Provincial conservation park
DRINKING WATER
Population drawing its drinking water from the river

Source: Centre d'études en enseignement du Canada (1986); Ministère de l'Environnement du Québec (1988*a*); Department of Fisheries and Oceans (1991).

Tourism and recreation

The Quebec tourism industry boasts economic returns of some $3 billion a year (Scott *et al.* 1989). The St. Lawrence plays a significant role in this industry, as the majority of tourist information facilities, historic sites, and tourist activities are concentrated in the St. Lawrence valley (see Box 19.4).

One study has shown that between 25 and 30% of Canadian and American tourists were attracted by outdoor activities (Morissette *et al.* 1985). Parks, wildlife reserves, and migratory bird santuaries are good means of promoting tourism while protecting the local natural heritage. Along the river are various municipal and provincial parks, the Saguenay Marine Park, and three federally operated parks: Forillon National Park in the Gaspé, Mingan Archipelago National Park Reserve on the north shore, and St. Lawrence Islands National Park in the Ontario portion of the river. In the freshwater section, 212 000 anglers devote a total of 2.4 million days a year to fishing, with annual catches totalling some 3 200 t, or 70% of all recreational and commercial fishing catches. Eighty percent of recreational fishing catches come from the Montreal area (Mailhot 1990).

The St. Lawrence could be a prime recreational area for residents of its shores. In the 1970s, 65 beaches, 95 campgrounds, and about 100 marinas were located on its shores (Comité d'étude sur le fleuve Saint-Laurent 1978). However, due to poor water quality close to cities, areas that can be used for recreational purposes are rare. Yet such facilities should exist in the immediate vicinity of urban centres for the benefit of local residents. Within the Quebec Urban Community, not a single beach could be opened in 1990 because none met the criteria of Quebec's Ministry of Environment (R. Bertrand, Ministère de l'Environnement du Québec, personal communication). Nevertheless, many summer vacationers shrug off the dangers of contamination and sometimes bathe close to industrial and municipal discharge sites, proving the need for recreational sites along the river.

In certain sectors, water quality has improved recently. Following the installation of a main sewer collector by the Montreal Urban Community in 1984, Cap Saint-Jacques beach, upriver from Rivière-des-Prairies, was reopened to bathers (B. Séguin, Montreal Urban Community, personal communication). A beach-park was inaugurated in 1990 on Notre-Dame Island, close to Montreal, thanks to a system of natural water purification. In the 1950s, the Montreal region alone boasted about 13 beaches, some of which should be reopened in the coming years (R. Gaudreault, Montreal Urban Community, personal communication).

BOX 19.1

Diversity threatened

All along the St. Lawrence, agricultural, industrial, and urban development has reduced or destroyed numerous plant and animal habitats. Recent changes to wetlands with exceptional ecological characteristics also threaten the survival of many species.

It is difficult to draw up a balance sheet that accurately reflects the status of Quebec's endangered species, because knowledge of species and their range is fragmentary. The Quebec government compiled lists of endangered species that have been incorporated into new legislation. A recent summary (Dryade Ltée 1989) found that the following species are endangered or threatened with extinction within a 1-km corridor on both sides of the river:

- about 300 species of vascular plants, including American hazel, swamp white oak, silky willow, blue iris, American ginseng, and wild leek; there is no list of rare or endangered Quebec mosses, lichens, or other nonvascular plants;
- 11 species of insects, including 9 lepidoptera and 2 ordonata (based on very sketchy data);
- 13 species of fish, which scientists fear face extinction, including copper redhorse, river mullet, and grass pickerel; the striped bass has already disappeared from the river;
- 19 species of reptiles and amphibians;
- 26 species of mammals (excluding those marine mammals that rarely enter Quebec waters); among the most critical cases are St. Lawrence beluga, bowhead whale, and the eastern cougar, all of which are on the point of extinction.

A preliminary status report prepared under the St. Lawrence Action Plan notes 15 species of birds in the St. Lawrence corridor that are vulnerable, threatened, or endangered. Three species face extinction: Peregrine Falcon, Piping Plover, and Loggerhead Shrike (Robert 1989). About 30 fauna species along the St. Lawrence are threatened (Groupe de travail sur les espèces prioritaires pour le PASL 1990).

The St. Lawrence beluga has been the cause of particular concern in recent years. At the turn of the century, there were 5 000 of these small white whales; today, there are a mere 350–750 (the lack of precision being due to survey difficulties) (Department of Fisheries and Oceans and Environment Canada 1989). At the outset, whale hunting was one of the main causes of this decrease; today, the beluga population is subject to pressures from changes to its habitat, industrial pollution, and disturbance by vessel traffic (Department of Fisheries and Oceans 1987). Since 1986, boaters have been required to refrain from purposely setting out to observe belugas; guidelines also exist to protect other species of whales (e.g., minke whale, fin whale, humpback whale, blue whale) from unnecessary stress.

A RIVER IN DANGER

The St. Lawrence is threatened. Human activities not only contribute directly to pollute and transform it but also affect natural phenomena that have an impact on the river (see Box 19.5).

Water pollution

Table 19.1 shows the five main types of pollution, their sources, their environmental impact, and the areas most affected. (Radioactive, thermal, acid, and mineral pollution are excluded from this list, as they are less of a concern for the St. Lawrence region overall.)

Wastewater and dirty snow

Municipal wastewaters are a major source of organic and microbial pollution. They may also contain toxic substances. It is possible to remove some of these pollutants by treating wastewaters before they are discharged. In 1984, only 7.7% of the urban population within the greater St. Lawrence watershed[1] was served by wastewater treatment facilities. This percentage climbed to 32.1% in the coastal basin of the gulf, whereas the figure for Canada as a whole was 54% (Statistics Canada 1986). Since 1988, the Montreal Urban Community has begun operating a wastewater treatment station that serves some 1.8 million individuals (and industries whose wastes are equivalent to those produced by a city of 1 million) (Montreal Urban Community 1991), which brings the percentage of the target population being served by wastewater treatment facilities in 1991 in Quebec to 40% (Ministère de l'Environnement du Québec 1991). The installation of a main sewer collector on Montreal's South Shore is slated for 1994; the two Quebec Urban Community treatment stations will be operational in 1992 and will serve some 500 000 individuals. According to forecasts for the provincial wastewater treatment program, the wastewater produced by more than 85% of the targeted population within the St. Lawrence watershed will be treated by 1994 (J. Carpentier, Ministère de l'Environnement du Québec, personal communication). (For further information on wastewater management in Canada, see Chapter 3.)

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[1] Includes the Ontario segment of the river.

Pollution resulting from dirty snow dumped into the St. Lawrence by riverside municipalities has attracted public attention since the early 1980s. This practice temporarily alters the physical and chemical characteristics of the water and its sediments. In the long term, this causes changes in aquatic communities, especially downriver from dumping sites (André and Delisle 1988). The provincial environment ministry has formulated a policy concerning disposal of soiled snow in order to reduce discharge of the pollutants it contains — for example, salt, abrasives, heavy-metal particles (lead, iron, zinc), phosphorus, oils, and grease. This policy stipulates that, by 1996, all municipalities must find alternatives to directly or indirectly dumping soiled snow into watercourses.

Industrial effluents

Quebec industries annually release 265 000 t of hazardous liquid chemical wastes, in the form of oil, grease, sludges, solvents, acids, PCBs, cyanides, metals, and so on, into the river and its tributaries (Ministère de l'Environnement du Québec 1983). The Montreal and Montérégie regions annually produce about 190 000 t of hazardous waste, which is more than 60% of the total for the province (Commission d'enquête sur les déchets dangereux 1990).

In Quebec, about 12 000 manufacturing installations process raw materials and release polluting substances. Among them, 2 300 seriously threaten water quality, 180 are the principal source of atmospheric pollutants, and 3 500 produce hazardous waste (Ministère de l'Environnement du Québec 1988*a*). Most of these installations of concern are situated on the shores of the St. Lawrence, and 900 are subject to regulation of their effluent by the Montreal Urban Community's water purification plant. A large number of others are not connected to municipal treatment stations and do not treat their effluent properly. The result is a major conflict of uses: the river is used as an industrial waste dump and, at the same time, as a source of drinking water.

To tackle this problem, the federal and provincial governments have implemented cleanup programs. In the 1970s, under the *Fisheries Act*, the federal government adopted regulations targeting the effluent of several industrial sectors such as oil refineries, pulp and paper mills, and chlor-alkali plants.

BOX 19.2

Water supply

In Quebec, 45 intakes draw drinking water from the St. Lawrence River, which supplies close to 3 million inhabitants in 104 municipalities, half of all Quebeckers. This water is treated and disinfected in filtration plants to make it suitable for human consumption, but it still contains microcontaminants, some of which may be toxic or carcinogenic (Ministère de l'Environnement du Québec 1989). In intensive farming regions such as Lanaudière (northeast of Montreal), the water contains ammonia nitrogen and organic substances capable of hampering disinfection operations by reducing the chlorine's bactericidal effect or causing smelly products to form, sometimes forcing residents to boil their water before drinking it. Recent discoveries have shown that the chlorine used by filtration plants reacts with certain organic compounds (ammonia nitrogen, organic substances) to form products that are potentially toxic (Ministère de l'Environnement du Québec 1988*a*). In the case of the St. Lawrence, problems stem mainly from the interaction of chlorine and organic substances (A. Riopel, Ministère de l'Environnement du Québec, personal communication).

The presence of contaminated sediments in some sectors of the St. Lawrence complicates the withdrawal of drinking water. These sediments are stirred up and suspended by dredging in the ship channel, waves, and vessel traffic, in which case they may once again contaminate open waters. There is serious danger of deterioration of the aquatic environment, and studies have shown that the PCB, DDT, and lead content of the riverbed and suspended sediments regularly exceeds Quebec's quality criteria (Champoux and Sloterdijk 1988; Germain and Langlois 1989; Langlois and Sloterdijk 1989). This is particularly true for the outlet of Lake Saint-François, on the Îles de la Paix in Lake Saint-Louis, and in the Sorel delta in Lake Saint-Pierre.

Municipalities are not alone in using the St. Lawrence as a water supply source. According to 1981 data for Quebec as a whole, the manufacturing industry is the province's largest water consumer, using 55.4% of the total, compared with 32.7% used by the municipalities (Bernier 1987).

Water quality is very important for industrial operations. Water polluted by metallic salts, for instance, clogs up heaters and cooling pipes and must be pretreated. Many industries use waters treated by the municipalities, but this water does not always meet the standards set by certain food sector firms, notably breweries.

One thing is clear: the more pollution, the more the need to treat the water, and the more expensive and complicated things become. Prevention is clearly the best solution.

Quebec's wastewater treatment program is a provincial initiative that was launched in 1978. More recently, the Quebec industrial waste reduction discharges program targets the principal sources of industrial pollution in air, water, and land. In June 1988, the Government of Canada launched the St. Lawrence Action Plan with a $100-million budget. Its primary goal is to reduce, by 1993, 90% of the liquid toxic waste being discharged into the St. Lawrence and Saguenay rivers by the 50 industrial plants considered to be the biggest polluters. These plants belong to the following five main industrial sectors: pulp and paper, metallurgy, chemical, petrochemical, and surface finishing. In 1991, under Canada's Green Plan (Government of Canada 1990), the federal government announced a program designed to strengthen efforts to clean up and restore the natural environment by preventing pollution in the Great Lakes and the St. Lawrence River.

Considerable headway has been made in the past 20 years in the pulp and paper and oil refineries sectors. Of Quebec's 56 pulp and paper mills, 15 of the mills targeted by the St. Lawrence Action Plan (all located along the St. Lawrence and Saguenay rivers) generate 40% of all suspended solids and biodegradable substances of industrial origin found in the St. Lawrence (Lalonde, Girouard, Letendre et associés Ltée 1990). They are also a major source of organic and toxic pollution (putrescible matter, fatty acids, and chlorinated phenols). The enforcement of federal and provincial regulations, combined with changes in manufacturing processes, has succeeded in substantially reducing pollutants. Between 1980 and 1989, the Quebec pulp and paper industry reduced its discharge of suspended solids by 57% and that of biodegradable substances by 35% (A. Grondin, Ministère de l'Environnement du Québec, personal communication).

BOX 19.3

Fish consumption

Be it mercury, DDT, mirex, PAHs, chlordane, or PCBs, the contaminants spewing into the St. Lawrence or its sources can accumulate in the flesh of fish and the tissues of other aquatic and semiaquatic organisms.

It is known that methylmercury concentrates in fish-eating fish. Health and Welfare Canada has set 0.5 ppm as the maximum allowable mercury content in fish sold for consumption, but this content is frequently exceeded in large predators (Sloterdijk 1990). In the Beauharnois region, northern pike caught in 1985 showed mercury contents of up to 2.5 ppm.

PCBs tend to accumulate in fatty fish and may hinder the growth of and even kill eggs as well as juveniles feeding on their own fat reserves. The allowable PCB content is 2 ppm, but higher concentrations have been observed in American eel and lake sturgeon (Sloterdijk 1979). Large fish caught in the Montreal region have shown a PCB content of more than 2–5 times the allowable rate (DesGranges and Thompson 1990).

According to their potential for biomagnification, certain pollutants discharged into the water and present in sediments and vegetation may accumulate in organisms and be magnified up food chains (invertebrates, plant-eating fish or birds, fish-eating fish, and animals), some of which include people.

Warnings on fish consumption sometimes recommend that certain species caught in the St. Lawrence should not be eaten more than once or twice a month, and that species caught in specific areas should not be eaten at all for fear of food poisoning. It is also strongly advised that children and pregnant or nursing women refrain completely from eating these types of fish.

Because "an ounce of prevention is worth a pound of cure," governments have tackled the problem of contaminants at the source by implementing regulations aimed at reducing the amount of pollutants discharged into the river, thus decreasing contamination of the biotic community. Fishing for American eel, a species that showed serious mercury contamination, was prohibited in the St. Lawrence from 1970 to 1973; 15 years later, eels contain almost no mercury and meet Canadian standards, which are among the world's strictest (Bourget 1984). However, the species continues to show high levels of PCBs and mirex (Lévesque and Pomerleau 1986).

Regulations adopted in the late 1970s targeting oil refineries led this sector to invest more than $100 million in the installation of purification systems. From 1972 to 1988, the discharge of suspended solids, oil, grease, and phenols dropped by over 80% due, in part, to new treatment systems and oil refinery shutdowns. Since the inception of the St. Lawrence Action Plan, other reductions have been observed: from 1988 to 1990, discharge of suspended solids, sulphurs, and phenols decreased by 23, 21, and 19%, respectively, despite a 6% increase in production (Fédida and Beaudoin 1991). Nevertheless, refineries and pulp mills continue to discharge considerable quantities of pollutants into the river, and existing regulations fail to govern several toxic substances considered a priority — namely, organic substances such as PAHs and chlorinated phenols.

In other unregulated industrial sectors, the situation is just as unsettling. Some firms in the metallurgy, surface finishing, and inorganic chemical sectors are among the biggest polluters. Concentrated along the St. Lawrence, primarily between Valleyfield and Bécancour, they discharge large quantities of suspended solids, heavy metals, and toxic pollutants into the river. Six of Canada's seven aluminum smelters are located in Quebec, with others pending. These smelters discharge fluorides, suspended solids, cyanides, heavy metals, and, in some cases, PAHs.

Agriculture

Farming is particularly intensive in the St. Lawrence lowlands, where over half (1 240 000 ha) of Quebec's prime agricultural land is found (Ministère de l'Environnement du Québec 1988*b*). From 1971 to 1986, pasture land diminished as areas devoted to field crops grew by 300–1 000%. This increase led to greater use of chemical fertilizers and pesticides, as well as to soil erosion and degradation (Ministère de l'Environnement du Québec 1988*c*). Livestock production is concentrated around the Yamaska, Saint-François, Chaudière, Richelieu, L'Assomption, and Etchemin rivers.

Intensive farming harms the quality of the St. Lawrence's waters. Current farming practices lead to soil erosion and the transport of abundant sediments into the St. Lawrence and its tributaries. The use of fertilizers often results in an excess of nutrients in watercourses, which, in turn, causes eutrophication and the proliferation of aquatic plants. In decomposing, these plants reduce the water's oxygen content and produce putrid odours and visual pollution. Discharge of animal excrement (solid and liquid manure and contaminated waters) is linked to the presence of pathogenic microorganisms in the water. Chlorinated organic pesticides (e.g., DDT) and herbicides also affect the aquatic environment because even trace quantities of some of them can cause physiological disorders and accumulate in the food chain. The Peregrine Falcon and Northern Gannet have both fallen victim to these products, which cause eggshell thinning and, consequently, lower hatching rates and declines in population (DesGranges and Thompson 1990).

Most sources of agricultural pollution are diffuse. Seepage and runoff carry pollutants such as organic matter, nutrients (nitrogen and phosphorus), trace quantities of heavy metals, pesticides, and microorganisms into watercourses. The harm these pollutants cause depends on how people use the water (e.g., drinking, bathing, or fishing) and whether it serves as an environment for aquatic species.

Manure is an excellent enrichment for agricultural soils as long as quantities do not exceed the retention capacity of the soil. Surpluses are estimated at 486 000, 334 000, and 570 000 t annually for the L'Assomption, Yamaska, and Chaudière river basins, respectively. Improper spreading techniques (after the growing season or in late fall) as well as incorrect manure storage can result in eutrophication and damage aquatic life. According to a Quebec survey conducted between 1982 and 1985, only 57% of farming operations complied with existing regulations (Ministère de l'Environnement du Québec 1988*c*). This led the Quebec government to implement a program for improving manure management. Microbial water pollution in rural areas, especially during hot dry spells in the summer, can be a health hazard for both people and animals that consume the water or simply come in contact with it.

Wastewaters from dairy farms are another source of agricultural pollution because they contain milk residue, chlorinated disinfectants, and polyphosphate-based cleaning products. They are generally dumped on the ground close to water supply points or enter watercourses via farm ditches.

Maritime transport and accidental spills

The St. Lawrence is a natural artery linking the North American heartland to the Atlantic Ocean. It served as the entrance to New France and had a great influence on the evolution of the road and rail networks that developed along its shores.

Maritime transport accounts for 5.6% of Quebec's gross domestic product (LAPEL Inc. 1989). The St. Lawrence Seaway includes, besides dams and canals, seven locks that allow boats to navigate the 72-m vertical drop in the water level between Lake Ontario and Montreal. Opened in 1959, the seaway makes the St. Lawrence a major route

BOX 19.4

Quality of life

Be it for tourism or leisure, the quality of life associated with the St. Lawrence is essential to Quebec's economic and social development. Increasingly, people are feeling the need to seek haven in a healthy environment that combines beauty, pleasure, and leisure activities. In this sense, the river and its shores constitute an asset that Quebeckers and tourists alike are beginning to discover. Here are some examples:

- redevelopment of the old ports of Quebec City, Trois-Rivières, and Montreal and the development of recreational, cultural, and commercial activities such as boat trips, shows, restaurants, boutiques, and other services; residents and tourists take great pleasure in these places, where they can revel in the river's beauty and enjoy a breath of fresh air;

- organization of cruises and excursions on the river;

- popular events focusing on the St. Lawrence and its resources: the Grandes-Bergeronnes Blue Whale Festival, the Matane Shrimp Festival, the Sorel Wild Game Festival, and the Quebec Winter Carnival, complete with its canoe race on the frozen river;

- development of new marinas, picnic areas, access roads, interpretation centres, hiking trails, and bike paths.

for shipping (mainly for grain, mining products, and manufactured goods). Half of the cargoes are destined for central Canada or originate there (Centre d'études en enseignement du Canada 1986).

Access to the North American continent and the relative proximity of northern European ports have favoured the growth of Quebec ports since 1959. Six of Canada's 13 major ports are located in the Quebec portion of the St. Lawrence River. By order of tonnage handled, they are Port-Cartier, Montreal, Sept-Îles, Quebec City, Baie-Comeau, and Sorel. Traffic at these ports has quadrupled over the past 30 years (Scott *et al.* 1989).

Merchant ships and oil tankers made more than 14 000 trips between Sept-Îles and Cornwall in 1989. Maritime transport is a valuable economic asset for Quebec; nonetheless, it represents a threat to aquatic ecosystems. From 1971 to 1988, 641 oil spills were recorded, 4 of which were of medium gravity — that is, they involved more than 1 000 barrels (Environment Canada 1989). The best known were those of the *Pointe-Lévis* at Matane in 1985 and the *Czantoria* at Saint-Romuald in 1988 (Groupe d'initiatives et de recherches appliquées au milieu 1989). In 1990, the *Rio Orinoco* ran aground near Anticosti Island, spilling over 700 barrels of hydrocarbons, which affected numerous river habitats.

Navigation is particularly difficult in certain areas of the St. Lawrence due to strong currents, constriction of the ship channel, and shallow water (Environment Canada 1989). The potential for oil spills or shipping accidents is highest in these sectors. In 1988, of the 111 million tonnes of cargo handled in St. Lawrence ports, 21% were dangerous goods — that is, products, materials, or organisms capable of harming the environment (Environment Canada 1990). Following hearings held in 1989 on oil tanker safety, recommendations were formulated to reduce the risk of

BOX 19.5

Pollution: it's not a new problem

As early as 1676, a Quebec police regulation ordered all butchers "not to tarry in taking all blood and offal down to the river," subject to a fine. In 1706, 23 industrial plants and manufacturing firms (e.g., food, breweries, sawmills, sugar refineries, distilleries) discharged their effluent directly into the St. Lawrence. In 1827, legislation adopted by Lower Canada stipulated that Quebec harbour inspectors shall point out "where the garbage could be dumped on the shore." In 1851 and 1856, legislation even served to spread the view that industrial and other uses of watercourses reflected affluence; a direct link was drawn between prosperity and pollution (Fleury 1973).

TABLE 19.1

Main pollution types, their sources, environmental impacts, and areas most affected

Pollution types	Sources	Environmental impacts	Areas most affected
Organic	•Organic waste of human, animal, and industrial origin, generated by agri-food and pulp and paper industries and municipalities	•Reduction of oxygen content of the water leads to the extinction of certain fish species •Foul odours •Eutrophication, which results in a proliferation of algae and aquatic plants	•Watercourses in the farming areas of the St. Lawrence valley •Lakes and bays receiving urban and industrial effluent
Toxic	•Toxic organic waste (pesticides, dioxins, and phenols) generated by the farming and industrial sectors •Inorganic toxic waste (heavy metals) generated by the chemical, metallurgical, mining, and surface finishing industries	•Immediate or long-term effects on organisms •Disappearance of certain species •Biomagnification that could affect people	•Mining regions •Tributaries crossing areas of intensive farming •Major industrial waste discharge sites •Watercourses suffering the combined effects of industrial and agricultural waste
Fertilizing	•Household and agricultural waste containing nutrients such as nitrogen and phosphorus •Nitrogen-based products generated by manufacturers of explosives and fertilizers	•Proliferation of algae and aquatic plants •Decomposition of aquatic plants, which reduces the oxygen content of water and creates an environment unfavourable to certain aquatic species •Unsightliness of lakes, rivers, and streams	•St. Lawrence's south shore, especially at the mouth of principal tributaries
Microbial	•Waste of human or animal origin, which leads to pathogenic organisms in the water (bacteria and viruses)	•Spread of infectious diseases •Makes recreational activities and shellfish collecting impossible	•Sites where household and municipal sewage are discharged into the water •Intensive livestock breeding areas
Visual	•Pulp mills and textile industry •Untreated municipal wastewaters	•Water discoloration, suspended solids, floating debris, styrofoam, etc. •Makes recreational activities impossible	•Urban areas

Source: Various publications of the Ministère de l'Environnement du Québec.

spills (e.g., double hulls, improved aids to navigation), but so far none have been adopted or incorporated into regulations (Public Review Panel on Tanker Safety and Marine Spills Response capability 1990).

Supertankers like the *Exxon Valdez*, which ran aground off the coast of Alaska in 1989, cannot travel on the St. Lawrence. However, an increasing number of oil tankers navigating on the St. Lawrence are carrying cargoes bordering on 1 million barrels, four times the volume spilled by the *Exxon Valdez* in Prince William Sound.

Physical changes caused by people

The following are the principal changes to the physical environment stemming from human activities in the St. Lawrence:

- *backfilling*: depositing materials in the river or on its shores (above the water level) for construction or urban development purposes;
- *draining*: changes to river habitats designed to prevent their submergence or shorten the natural period of submergence; land recovered in this manner is generally used for farming;
- *dredging*: scraping or cleaning of the riverbed for maintenance of the ship channel,[2] harbour facilities, marinas, and shipyard slips;
- *dumping dredged material*: disposal of dredged material in open waters; depending on the size of particles and the strength of the current, these materials can be carried downriver;
- *change to the flow*: any local change to the river's flow by some structure (e.g., wharf, boom, transmission line, marina) or a backfill.

The aquatic environment has been altered extensively between Montreal and Sorel by pollution, shore backfilling, and drainage, not to mention changes in flow resulting from the islands created for Expo '67 and the L.-H. Lafontaine tunnel-bridge in the Montreal region, Sternes Island in Lake Saint-Pierre, and the Bécancour, Portneuf, and Gros-Cacouna wharves.

Work related to maritime transport, including the widening of the ship channel in the mid-1950s, changed the river's configuration in a good many places. Every year, some 170 000 m^3 of dredged material are extracted during annual maintenance work in the channel. The canals, dams, locks, and mechanical effects of vessel traffic have also changed the dynamics of the river. Their cumulative impact has not been assessed, but the main repercussions are known. They are changes in the flow, which alter the water regime and heat balance in specific sectors, disturbance of the migration of certain fish species, and changes in the structure of fish communities (Robitaille *et al.* 1988).

There are few major electric generating stations along the St. Lawrence. The Tracy thermal power station, near Sorel, operates on fuel oil, and Gentilly II, across from Trois-Rivières, is a nuclear power generating station. Both are of secondary importance in Quebec's power grid. Four hydroelectric power stations are located along the river in Quebec: Beauharnois, Cèdres, Rivière-des-Prairies, and Carillon. The Moses-Saunders power station, upriver in Ontario, provides electricity for the Cornwall region. The capacity of these stations fluctuates around 3 480 megawatts (Scott *et al.* 1989). The river's flow rate is stabilized mainly by adjustments at the Moses-Saunders station, which in turn affects sedimentation and animal and plant life. Stabilizing spring flooding, for example, changes the nature of marshes and affects choice feeding and breeding grounds of numerous wild species of fauna.

The loss of wetlands is also due in part to human activities. Environment Canada (1985) drew up a summary of existing data on wetland gains and losses along the St. Lawrence, Ottawa, and Richelieu rivers. Net losses of 3 643 ha between 1950 and 1978 represent 6.2% of the total surface area of wetlands inventoried in 1950 and correspond to 360 km of shoreline over a 100-m corridor. Losses have declined since 1965 but continue nevertheless, affecting some regions more than others. Between 1966 and 1981, the net loss in wetlands in the Montreal region was 392 ha, or 6.7% of the total surface area inventoried in 1966 (Champagne and Melançon 1985), compared with a loss of only 1.6% for the St. Lawrence as a whole between 1965 and 1978 (Environment Canada 1985).

Natural phenomena affected by human activity

Erosion

Erosion of the river's shoreline results from the destruction of soil aggregates by rain, waves, wind, ice, and flooding, not to mention human activities (e.g., alteration of the banks, backfilling). The principal factors dictating the extent of water erosion are rain intensity, ground slope, vegetation covering, soil type, and soil state. Recent studies show that all the St. Lawrence's intertidal marshes have been affected by erosion to some extent (Lauzon 1989), although they are still among the world's most productive natural environments and support very diverse wildlife and vegetation. Therefore, their erosion may have ecological repercussions. The direct cause of erosion in the estuary and the gulf is water (waves and ice), though certain biological factors (e.g., birds digging for tubers) and human activities (e.g., ships and their waves, all-terrain vehicles, farmland drainage) also play an important role (Dubreuil 1989).

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[2] The ship channel must be dredged regularly over 200 km: 170 km between Montreal and Quebec City and 30 km downriver from Quebec City.

In the river basin, the loss of vegetative cover is the principal cause of soil erosion in farming areas. Suspended solids carried with the eroded soil can change the nature and texture of riverbeds, clog up spawning grounds, reduce diversity and productivity of bottom-dwelling species, obstruct water flow, and, ultimately, make dredging necessary. In addition, erosion and leaching of soils treated with fertilizers or pesticides lead to eutrophication and cause toxic pollution. It is estimated that in the watershed of the Yamaska River — a tributary of the St. Lawrence that flows through an intensive farming area — 60% of the annual phosphorus load comes from croplands, which cover only 36% of the watershed's total surface area. Water erosion caused by precipitation and runoff is responsible for 85% of this load (Ministère de l'Environnement du Québec 1988*b*).

Climatic change

A recent study (LAPEL Inc. 1989) allowed researchers to analyze the impact of the greenhouse effect (i.e., the temperature rise linked to the projected increase in the atmosphere's carbon dioxide content over the next 50 years) on the St. Lawrence. Its main repercussions are expected to be a drop in the water levels of the river proper and estuary and a rise in the water level from the middle estuary to the gulf. This phenomenon will occur due to the reduction in the supply from the Great Lakes and by increased water evaporation in the river proper and estuary. The rise in the downriver portion will result from glacier and ice cap melting and the expansion of the oceans.

The greenhouse effect could also cause surface water acidification, given that the chemical balance of the aquatic environment is closely linked to atmospheric carbon dioxide concentrations: carbon dioxide reacts with water to form a weak acid where air and water meet. The rise in atmospheric carbon dioxide is expected to cause a slight drop in the water's pH level. Acidification of the aquatic environment and acid precipitation could increasingly contaminate aquatic organisms through the increased solubility of metals in acidic surroundings. Upriver from Quebec City, we can apparently also expect the reduced flow to alter water quality given the water's reduced capacity to dilute pollutants.

THE STATE OF THE RIVER

A complex diagnosis

The St. Lawrence's size and the various factors threatening its quality make it difficult to assess its state. The "healthy river" concept may vary depending on whether the river is being assessed as an environment for bathers, riverside residents, or sturgeon. For instance, in a given sector, water quality may improve for certain criteria or usages (industrial water supply) but deteriorate for others (bathing, fishing). Ultimately, any effort to assess the state of the St. Lawrence is bound to encounter problems in data interpretation, especially for trends in time (seasonal, annual) and space.

Not a pretty picture

So far we have discussed the main elements reflecting the state of the environment for the St. Lawrence: loss of wetlands, sediment contamination, threats to diversity of flora and fauna, change in the composition of commercial fish catches, temporary or permanent closing of beaches, and so on. Each of these elements tells us something about the state of the river, but no single one tells the complete story. For this reason, the St. Lawrence Centre is preparing a program that will assess the health of the river's ecosystems based on indices of biotic integrity. The Centre is also assessing the toxic load entering the St. Lawrence.

The following is a brief assessment of the current situation and the trends in time for each pollution type shown in Table 19.1. As a rule, organic pollution tends to be localized — for example, downriver from the discharge site of a pulp and paper mill. Currently, the waters of the St. Lawrence show local degradation, which may threaten the survival of certain organisms. The longer term should see local improvements with the onset of new pollution control programs. However, an industrial sector like that of pulp and paper remains critical because it discharges approximately three times more biodegradable organic matter into the St. Lawrence than the entire population of the province of Quebec (Bolduc *et al.* 1986).

Toxic pollution is the most complex form of contamination given the many different substances involved. We know little about the current concentrations or ecological impact of organic products, particularly PAHs, dioxins, and chlorobenzenes. Persistent toxins continue to accumulate in the environment with unknown repercussions. The outlook is hardly encouraging given the high toxicity of even trace amounts of certain substances. The St. Lawrence Action Plan, which aims to reduce industrial liquid toxic waste, contributes to better understanding of the phenomena involved.

Nitrogen and phosphorus are the main culprits in nutrient enrichment. Phosphorus concentrations in the environment have decreased overall owing mainly to regulations governing the phosphorus content of detergents and a reduction in phosphorus from the Great Lakes. Nitrogen concentrations, on the other hand, are on the rise in certain agricultural regions (Désilets *et al.* 1988). The treatment of municipal wastewaters will, no doubt, improve the situation, but reducing nutrient enrichment also requires the use of proper growing techniques and proper manure storage systems (Ministère de l'Environnement du Québec 1988*c*).

Microbial pollution is linked primarily to the discharge of municipal wastewater, but livestock production is also to blame. Between Cornwall and Quebec City, the bacteriological quality of the St. Lawrence's waters, traditionally measured through fecal coliform concentrations, leaves much to be desired. In outlying regions (for example, the Gaspé and the North Shore), microbial pollution can lead to closure of clam-digging areas. Elsewhere, it closes down beaches. The positive effects of Quebec's wastewater treatment program can, however, be felt. Because the wastewaters of the Island of Montreal's southwest basin are now treated, the water quality on northern Lake Saint-Louis has improved considerably (Montreal Urban Community 1989). As other treatment stations become operational, the situation should improve even more within a few years. But as long as municipalities continue to dump their untreated wastewaters into the river and farming techniques are not improved, local problems will persist.

Floating debris and other forms of visual pollution, such as the proliferation of aquatic plants, are also linked to discharge of municipal wastewater. Downriver from untreated municipal discharge sites, it is not uncommon to see nonbiodegradable tampon applicators (Lamoureux 1989) and latex condoms. Quebec's wastewater treatment program should eliminate much of this type of waste in areas where wastewaters are not yet treated.

A LONG-TERM COMMITMENT

Ecosystems are complex and evolve much more slowly than the rate of human-induced change. Years may go by before the full effect of an environmental impact manifests itself. The same is true for remedial measures: their effects on the overall ecosystem are not likely to be immediate, so it is sometimes difficult to convince the parties involved of the need to implement them.

The integration of the environment and the economy

Attempts to remedy environmental problems almost always run up against the issue of short-term profitability. Canadians need a better understanding of the relationship between the environment and the economy if they are to implement effective remedies, although these remedial actions may be economically restrictive in the short term. In the long term, however, they will have significant positive effects.

Thus, reducing toxic industrial waste may initially have a negative impact on the economy, owing to higher production costs and consumer prices. However, improving the quality of the aquatic environment is profitable in the medium and long terms, because it cuts down on water treatment costs and promotes regional economic growth through increased tourism and recreation and better overall quality of life. The imposition of new standards encourages more and more industries to change their processes and to include in their goals research on, and adoption of, technologies that promote both productivity and respect for the environment. In many cases, the implementation of new production processes using "clean" technologies is profitable even in the short term.

Resource conservation aimed at long-term profitability is a social concern that requires action by the various levels of government, the public, and industry. The environmental challenge facing industry is increased by the fact that North American firms generally target short-term profitability.

Essential cooperation

The St. Lawrence and the drainage basins supplying it cover a vast area falling under several jurisdictions. The river straddles the Canada–U.S. border, covers part of Ontario, and crosses Quebec from west to east. In Quebec, 44 regional county municipalities are located along the St. Lawrence, in addition to the urban communities of Montreal and Quebec City. Many different groups are involved in its preservation: apart from municipal, regional, provincial, national, and international government organizations, there are environmental protection agencies, commercial and industrial firms, research centres, interest groups, and individuals (Table 19.2).

The number and diversity of those involved in safeguarding and enhancing the St. Lawrence often lead to administrative overlaps, and the duplication in some areas of federal and provincial jurisdiction simply makes the problem worse. In June 1989, a major step was taken with the signature of an agreement coordinating the efforts of various cleanup programs set up by the provincial government and the federal government's St. Lawrence Action Plan.

The interests of those involved in safeguarding and enhancing the river may also diverge: proposed wetlands conservation may conflict with planned farm drainage or wharf construction. Because they are interdependent yet extremely diverse, all measures aimed at protecting and enhancing the St. Lawrence must be coordinated to ensure that they are compatible and effective.

The federal and provincial governments invest millions of dollars in joint cleanup, rehabilitation, and enhancement programs targeting the St. Lawrence. The St. Lawrence Action Plan divides the river into 23 zones of priority interest to make it easier to understand the influence of local human activities, to highlight the resources and practices in each zone, and to elicit a commitment to action from partners in that zone. Another program of the St. Lawrence Action Plan, the creation of the Saguenay National Marine Park, is the result of an agreement signed in 1990 by the federal and provincial governments. It is aimed at protecting the exceptional flora and fauna in this region, and it will also help to ensure the survival of the beluga.

TABLE 19.2

List of main groups involved in safeguarding and enhancing the St. Lawrence River

Groups	Mandates/objectives	Programs
International Joint Commission	•Management of boundary and transboundary waters	•Financing studies on the state of the river's waters on both sides of the Canada–U.S. border
Federal and provincial governments: Environment Canada, Department of Fisheries and Oceans, Industry, Science and Technology Canada, Ministère de l'Environnement du Québec, Ministère des Transports du Québec, and Ministère du Loisir, de la Chasse et de la Pêche du Québec	•Administration of a variety of legislation, including the *Fisheries Act*, the *Canadian Environmental Protection Act*, Quebec's *Environmental Quality Act* •Ninety percent reduction, by 1993, of all toxic liquid waste generated by the 50 most polluting industries •Conservation, protection, rehabilitation, and enhancement of species, ecosystems, and river resources •Development of new industrial techniques •Improvement of the quality of the waters of the St. Lawrence	•St. Lawrence Action Plan (coordination of federal and provincial efforts) •Fish habitat management policy •Quebec wastewater treatment program •Integrated St. Lawrence enhancement plan •Program to reduce industrial releases •Habitat protection and resource management
Research centres and universities	•Increasing knowledge of the aquatic environment •Exploration of new avenues to ensure environmental protection	•Studies on ecotoxicology; sediment/water interaction; nutrient and pollutant behaviour; watercourse modelling
Groupe d'initiatives et de recherches appliquées au milieu (GIRAM) (CEGEP de Lévis-Lauzon)	•Research on environmental setting •Action on topical issues •Regional action	•Symposium on enhancing the St. Lawrence, highlighting its fragility and vulnerability
Société de développement économique du Saint-Laurent (SODES)	•Economic development of the St. Lawrence in keeping with environmental imperatives	•Member of executive and technical committees for the Project de mise en valeur du Saint-Laurent •Creation of Tourism, Recreation, and Environment Committee •Organization of symposiums and round tables •Creation of the Conseil québécois du nautisme
Industries and private sector	•Enforcement of new standards governing pollutant discharge into the river •Maintaining the industry's corporate image	•Investment of new funds to seek cleaner manufacturing processes
Regional county municipalities, Montreal and Quebec City urban communities, municipalities	•Development of shores to exploit the river's recreational and tourism potential •Treatment of municipal wastewaters	•Plans for developing the shores and river access roads •In some cases, regulation of private developments along the river
Environmental groups: Union québécoise pour la conservation de la nature (UQCN), Corporation de protection de l'environnement de Sept-Îles, Corporation pour la mise en valeur du lac Saint-Pierre, Centre for the Great Lakes, Linnean Society of Quebec, STOP, Société pour vaincre la pollution, Greenpeace, etc.	•Conservation and enhancement of the St. Lawrence: maintaining ecological processes, preserving genetic diversity, sustainable harvesting of species, sustainable use of ecosystems, and public awareness	•St. Lawrence strategy: portrayal of status of natural and social ecosystems •Granting of Béluga and Pollution prizes •Lawsuits against polluters •Public awareness and environmental vigilance and cooperation
Interest groups and individuals	•Protection of shores and improvement of water quality	•Periodic formation of movements, some within the Quebec Federation of Associations for the Protection of the Environment of Lakes (FAPEL) •Integration of water quality concerns with parallel objectives (canoe-camping or canoe-kayak associations) •Participation in waste recovery and preservation of the natural environment

Growing numbers of awareness campaigns by government agencies, non-government organizations, and interest groups are aimed at changing public attitudes and daily behaviour affecting the environment. It is within this framework that the St. Lawrence strategy implemented by the Union québécoise pour la conservation de la nature was formulated; the program encourages Quebeckers to define concrete local, regional, and provincial measures for managing, safeguarding, and rehabilitating the river.

CONCLUSION

For over a decade, various groups have been working to restore and protect the St. Lawrence. At the same time, the ongoing efforts of environmental protection groups have made the public aware of the precarious state of the river.

Existing programs aimed at safeguarding the St. Lawrence are already showing results. A number of pollutants are on the decline, and water quality should improve over the coming years. Despite these encouraging signs, however, the toxic waste issue is alarming, judging by warnings not to consume certain species of fish, threats to the survival of the St. Lawrence beluga, high concentrations of DDT in Peregrine Falcon eggs, and so on. It would be utopian to think that the river could be restored to its original state as long as pollutant loads exceed its purifying capacity.

Pollution knows no boundaries. The programs implemented in Quebec cannot solve the problem of pollutants entering the river from the multijurisdictional waters of the Great Lakes or the St. Lawrence's upriver segment. The concentration of mirex in American eel from Lake Saint-Pierre, for instance, is alarming, and the river's only known source of mirex is Lake Ontario (see Chapter 18). Airborne pollutants from Ontario and the United States are also cause for concern.

Permanent losses continue to pose problems: species and wetlands are disappearing as a result of changes to natural ecosystems caused by human activities. In the very long term, it may be possible to rid the St. Lawrence of pollutants, but it will never be possible to restore a species that has become extinct.

The St. Lawrence, one of the jewels of our natural heritage, has always been an integral part of the Canadian and Quebec context. Unfortunately, the river's health has deteriorated. Sustainable development of the resources of the St. Lawrence thus depends greatly on proper management.

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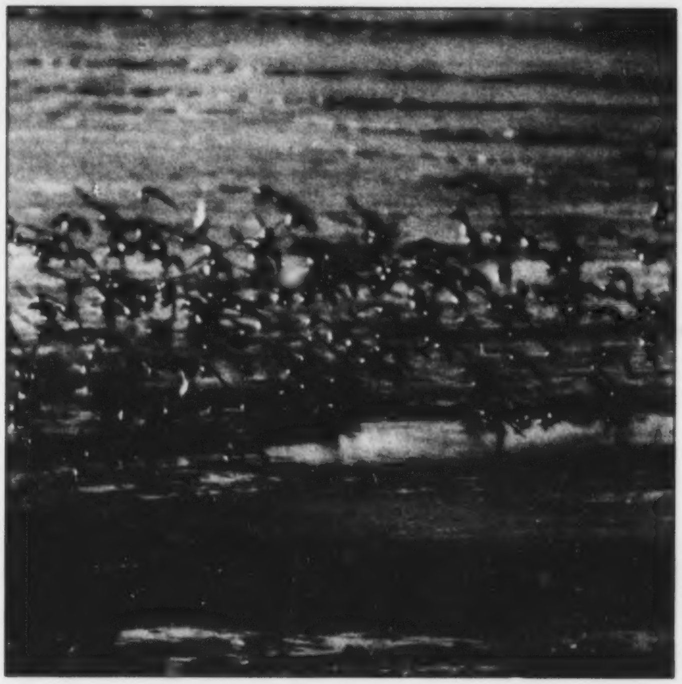

COURTESY OF M.A. BENNETT

HIGHLIGHTS

The salt marshes of the upper Bay of Fundy have shrunk dramatically since the arrival of Europeans in the 16th century. Over the centuries, settlers diked and drained 90% of the original salt marsh for agriculture, with resultant loss of wildlife habitat.

■

In the last half of this century there has been a decline in agricultural use of the dikeland, due to economic factors. Some attempt has been made to recover habitat for wildlife, through the creation of freshwater wetlands on dikelands.

■

The wetlands of the region — mudflats, salt marsh, and freshwater marsh — are of national and international importance as waterfowl breeding and staging habitat, and they form a critical link in the international network of habitats for migrating shorebirds.

■

Local communities are working on economic development strategies based on nature-related tourism.

■

Land-use planners are encouraging multiple-use strategies to optimize dikeland benefits and, at the same time, minimize direct competition between the dominant land users, namely, agriculture and the wildlife conservation sector.

■

Key wetlands have been designated as protected areas.

■

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INTRODUCTION

The shores of Shepody Bay and the Cumberland Basin, from Cape Enrage, New Brunswick, to Joggins, Nova Scotia, are ringed by salt marshes and diked fields. Three centuries ago, when the Acadians built the first sod dikes in the upper Bay of Fundy area, the expanse of salt marsh was nine times larger than it is today. Although many Maritimers still refer to the diked wetlands as marsh, the land that now lies behind the dikes might best be described as a maritime prairie, it so resembles western Canadian grasslands (Jackson and Maxwell 1971).

This area owes its distinctive qualities, first, to the unique geological and hydrological features of the region that ultimately gave rise to the world's highest tides and the marsh-building process and, subsequently, to the long tradition of profound human alteration of the environment. Today, some of the more fertile dikeland, closest to the dikes and sea, is lying idle, and freshwater wetlands are being created on more poorly drained dikeland soils farther from the coast. The creation of freshwater impoundments on abandoned agricultural land, which itself was once salt marsh, is an interesting twist in the centuries-old history of land management in the upper Fundy.

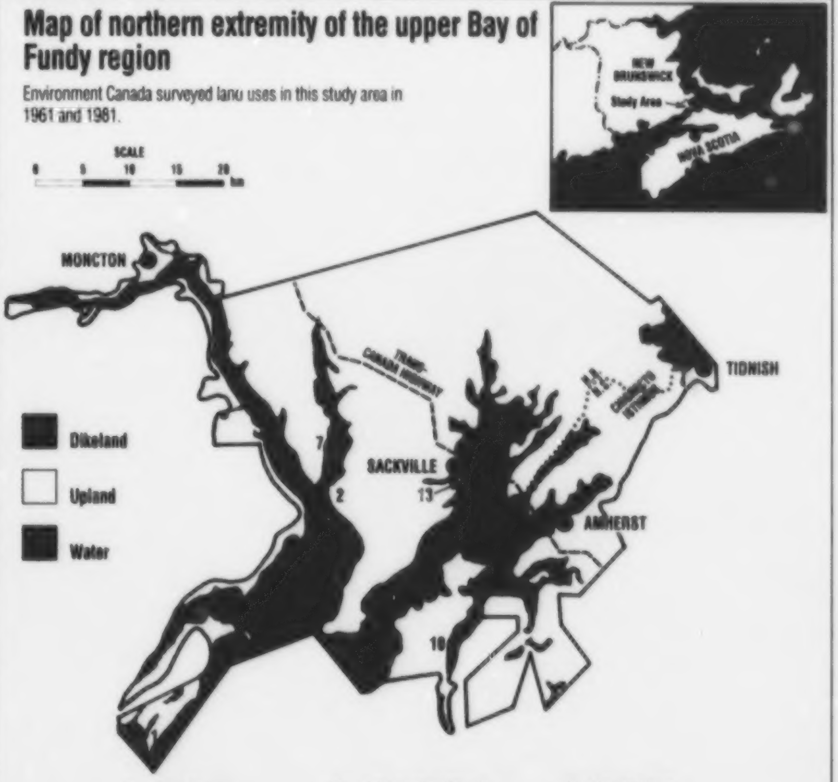
A recent study of land use in a 2 137-km² area around Shepody Bay and the Cumberland Basin (Fig. 20.1) included an analysis of the changing land-use patterns on 267 km² of the dikeland between 1961 and 1981 (Environment

> “
>
> Tantramar, the river, deep, tidal
> moving on a March morning,
> high as she goes
>
> there in the banked and thrown ice
> the leaking limits of the marsh
>
> move free in their melting,
> leaving crusts
> to the shudder of tidal might.
>
> the sea-force moves and makes
> a landscape
> empty in a winter season of
> searching birds,
>
> it is a happening of nature we try
> to chart
> and plot our way to nearer
> understanding
>
> but it is the going on of the place
> the flowing by of life, so close,
> so close
>
> ”
>
> — Douglas Lochhead, *in* Lochhead and Holownia (1989)

FIGURE 20.1

Map of northern extremity of the upper Bay of Fundy region

Environment Canada surveyed lanu uses in this study area in 1961 and 1981.

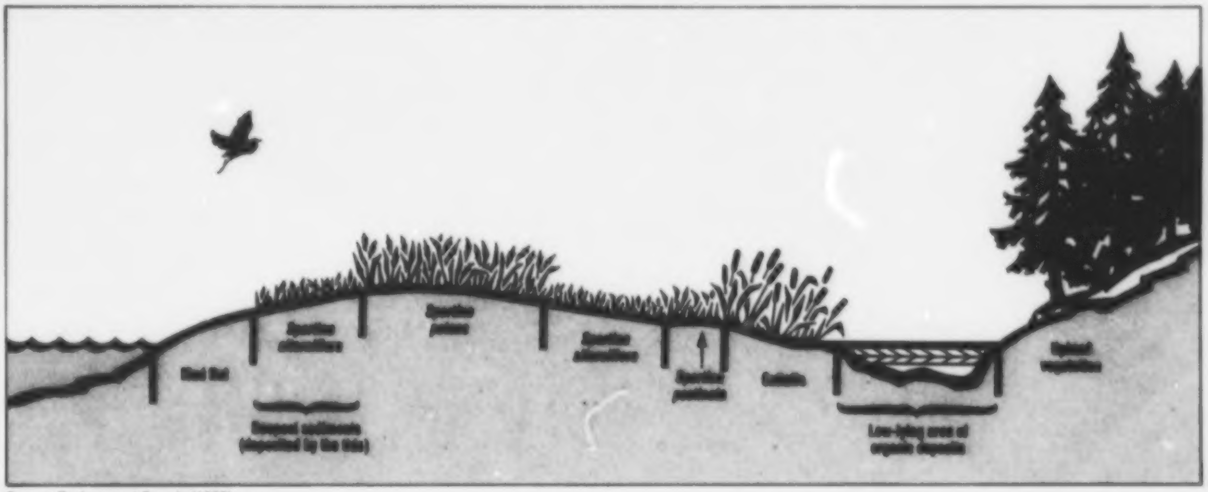


1 Cape Enrage
2 Dorchester Cape
3 Fort Beauséjour
4 Fort Lawrence/LaPlanche River
5 John Lusbys Marsh
6 Marys Point
7 Memramcook River
8 Minudie Marsh
9 Petitcodiac River
10 River Hébert
11 Shepody Marsh
12 Tantramar Marsh
13 Ram Pasture Marsh

Source: Environment Canada (1990).

FIGURE 20.2

Landscape sequence in undiked salt marsh in the upper Bay of Fundy mudflat



Source: Environment Canada (1990).

Canada 1990). This chapter highlights the trends in land use over the 20-year period and sets them in a context of the natural history of the lowland area and the 350-year history of intensive human use of these fertile wetlands. Although the chapter shows that there have been slight increases in wetland habitat for wildlife in the last few years, the overall trend in the upper Bay of Fundy and, indeed, all along Canada's Atlantic coast has been loss of wetlands. Since European settlement, 65% of Atlantic coastal marshes have been lost, mainly to agricultural expansion (see Chapter 7).

A GLANCE BEHIND

The name "Chignecto" means "great marsh district" in the Micmac language. Early European records identify Midgic, on the Jolicure Lakes, as a major native encampment. The tidal and fresh waterways of the Chignecto isthmus also served the Micmac as a major transportation link between the Bay of Fundy and Northumberland Strait (Ganong 1899, cited in Royal Society of Canada 1983).

The Acadians who arrived at the isthmus of Chignecto in the early 1670s found a salt marsh covering an area of close to 150 km^2 (Teal and Teal 1969). They immediately recognized the fertility of marshland soils. "[There are] many large and beautiful meadows extending farther than the eye can reach.... The country was for the most part agreeable and… would be very fertile if cultivated," wrote one French colonist.

Immigrating mainly from the Poitou area on the west coast of France, these early settlers were already familiar with the tidewater environment (Fig. 20.2) and the methods of making it accessible for agriculture (Daigle 1982). Rather than clear the forested uplands, the Acadians chose to dike, drain, and farm the wetlands.

The Acadians isolated areas of salt marsh from the action of the sea by constructing earthen dikes faced with sod. Key to the Acadians' land conversion strategy was the "aboiteau," a wooden conduit or culvert built into the base of the dike. It was fitted with a swinging door or gate on the seaward side that allowed excess fresh water to drain from the fields during low tide without letting in salt water returning with the tide (Fig. 20.3). The enclosed areas were gradually converted to freshwater marshes as the salt content was washed out by surface fresh water. The entire process of diking, ditching, and draining required at least 2–3 years before the newly established dikeland could be used for crops or pasture.

The Acadians fertilized their soils by "tiding" — periodically allowing the tides to flood the drained marshland. Tiding could add 2–3 cm of nutrient-rich sediments to dikeland soils each year. Acadian farmsteads consisted of a mixture of dikeland and upland, to provide both fertile dikeland and a dry building site on the adjacent uplands.

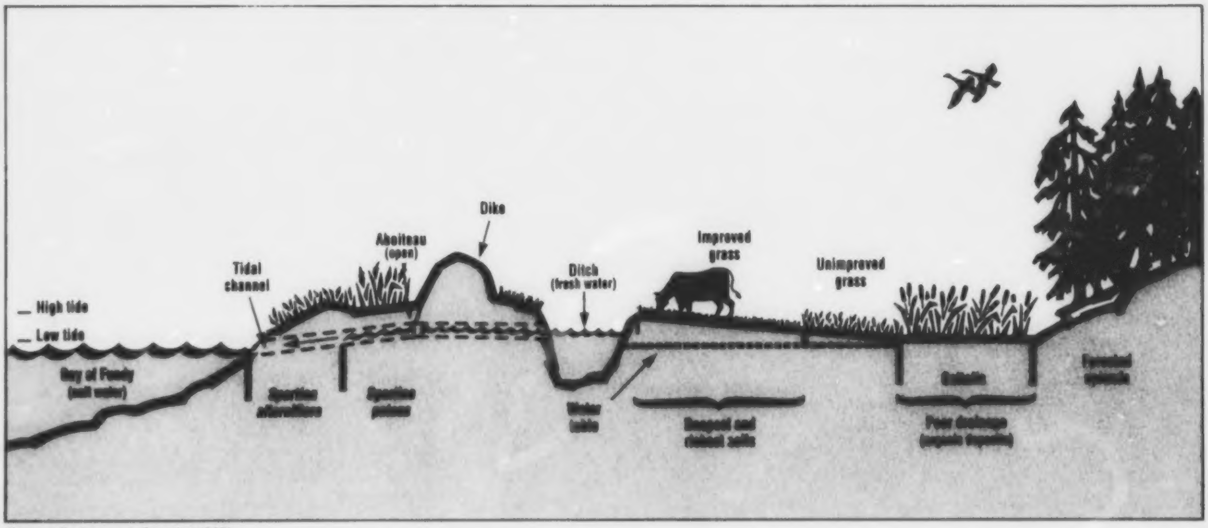
Tantramar heydays

The marshland farms of the Acadians provided nearly all their material needs. In addition, during much of the 17th and early 18th centuries they had surplus grain to trade with the English colony of Massachusetts (Daigle 1982).

In 1755, the French-speaking Acadians were deported from their rich farms by British soldiers. The fortunate settlers who inherited their engineering

FIGURE 20.3

Landscape sequence in upper Bay of Fundy wetlands after diking



Source: Environment Canada (1990).

works arrived in waves. New England planters (1760–65), Yorkshire farmers (1772–74), and, finally, United Empire Loyalists (1783–84) occupied the vacated lands and expanded the diked areas by advancing the dikes seaward. During the 19th century, the rate of conversion of salt marsh to dikeland accelerated considerably. The expansion of dikes and construction of ditches and canals for drainage took on more of the character and scale of public works, and, even today, the Aulac River dike system, begun in 1804, serves as the Canadian National railbed and protects the Trans-Canada Highway.

By the early 20th century, marsh hay had become the main cash crop of the Chignecto area. Horses were the essential source of energy for farming, mining, logging, and short-haul transportation — and horsepower is fuelled by hay. The farmers of the Tantramar and neighbouring dikelands not only consumed their crops locally, but shipped large quantities of hay to Halifax, Saint John, and as far away as Boston (Nova Scotia Department of Agriculture and Marketing 1987).

A war against the sea

Hay prices peaked at $28.00 per ton (about $31.00 per tonne) in 1920, but the boom was a prelude to hard times. With the replacement of the horse by the internal combustion engine, the market value for hay plummeted. This slump, coupled with the general economic malaise of the Great Depression, resulted in less money being spent on dikeland maintenance and virtually none on building new dikes. By 1943, large tracts of arable land returned to salt marsh owing to the deterioration of the dikes.

In an attempt to stem additional losses of agricultural land, the federal government introduced the *Maritime Marshland Rehabilitation Act* (MMRA). Under this program, the federal government assumed responsibility for the construction and maintenance of dikes and aboiteaux in the Maritime provinces. Between 1948 and 1970, some 333 km^2 of dikeland were protected, 77% lying within the Chignecto Bay area of upper Fundy. New or renewed dikes were completed, and major tidal control structures were installed on the Shepody, Memramcook, Petitcodiac, and Tantramar rivers (Fig. 20.1).

This "20-year war" to save the region's most fertile soil was largely successful (Nova Scotia Department of Agriculture and Marketing 1987), although some previously diked areas, such as John Lusbys Marsh west of Amherst and the Ram Pasture Marsh southeast of Sackville (Fig. 20.1), were never rediked due to extensive erosion. These areas have reverted to natural saltmarsh ecosystems. With the erection of tidal control structures on tidal rivers, the pattern of marsh agriculture was changed. Tiding has traditionally involved breaching a dike along a tidal river. When the tides ceased to enter a river, the farmers along its banks lost the option of sustaining fertility through the periodic application of tidal sediments. Applications of manure, chemical fertilizers, and agricultural lime became common procedures on fields where they were once unnecessary. Technology brought other changes. In the 1970s and 1980s, the major initiative in dikeland agriculture was landforming, a method of contouring the land to improve drainage and, at the same time, replace old drainage ditches — which prevented efficient use of modern machinery — with grassed waterways.

UPPER FUNDY TODAY

Human population and industry

The upper Bay of Fundy has always been rather sparsely settled. In 1750, just prior to their forcible deportation, there were an estimated 2 800 Acadians living in the upper Fundy region (Daigle 1982). Today, the population is concentrated in two towns, Sackville, New Brunswick (population approximately 6 000), and Amherst, Nova Scotia (population approximately 10 000) (Fig. 20.1). In addition, there are several villages and a scattering of farms and rural homes along the margin of the marshes and at the base of the gently rolling uplands and ridges that overlook the upper Fundy wetlands. The city of Moncton, New Brunswick (population about 90 000 including the surrounding municipalities), located on the banks of the Petitcodiac River, exercises a significant influence on land use and social and economic activities in the region. The isthmus of Chignecto, the landbridge connecting peninsular Nova Scotia to mainland New Brunswick, is an important transportation and communications corridor. The dikes protect the Canadian National rail line and Trans-Canada Highway, as well as electrical transmission lines and the Radio Canada International shortwave transmission facility.

At the beginning of this century, Sackville, New Brunswick, and Amherst, Nova Scotia, were busy industrial centres where cast-iron foundries and a variety of lighter manufacturing enterprises prospered. Today, very little of that manufacturing base remains, and it is highly probable that environmental contamination from industrial sources is considerably less now than in the past. In comparison with other more heavily populated and industrialized regions, upper Fundy is still relatively unstressed.

However, point sources of contaminants affect environmental quality in four places in the region: Moncton, Dorchester Cape, Sackville, and Amherst. Though these population centres and their associated industries, including metal finishing plants, are located near sensitive waterfowl and shorebird habitat, to date no effect on migratory birds has been detected, and the hazard to other wildlife and saltmarsh habitat is considered low (Lane and Associates Ltd. 1987).

The wetlands

Twice a day, the turbulent waters of the Bay of Fundy rush in and out of the two narrow arms of Chignecto Bay known as Shepody Bay and the Cumberland Basin (Fig. 20.1). At an average range of 11 m and a maximum of about 15 m, these are among the highest tides in the world: two-thirds of the Cumberland Basin empties at low tide, as does about half of Shepody Bay (Gordon and Desplanque 1983).

Between the normal limits of high and low tide lie the intertidal mudflats — vast, gently sloping expanses of reddish mud broken by deep-sided creek channels. The salt marsh, a green ribbon of vegetation that fringes these seemingly barren flats, is connected to the marine ecosystem only briefly at high tide. But however brief, the continual flooding is crucial to marsh life and the marsh-building process.

In 1903, native son W.F. Ganong described the dynamic nature of the Fundy marshes: "[They] have been, and still are being, built... out of inorganic mud brought in from the sea by the rush of the tides, whose height is the determining factor in their height." Over the past 6 000 years, there has been a buildup of nutrient-rich sediments in the marshes to a depth of 40 m or more.

In addition to the turbulence of the tides and the restless relationship between land and water, the area is characterized by its importance as wildlife habitat. American shad from the entire eastern seaboard come to the muddy Cumberland Basin to feed every summer, and each year these and other anadromous fish, such as salmon, gaspereau, and striped bass, make their way up the region's tidal rivers to spawn (Dadswell *et al.* 1984).

Although at first glance the mudflats may look lifeless, they are teeming with organisms. Bottom-dwelling algae flourish on the surface of the flats, and tucked into the mud is a cornucopia of invertebrates, dominated by mudshrimp (*Corophium volutator*). The Gulf of Maine and the Bay of Fundy are the only places in North America where this shrimp-like creature is found, and the densities observed in the Bay of Fundy are higher than those seen anywhere else in the world. Mudshrimp are the main food supply for immense flocks of migrating shorebirds, especially Semipalmated Sandpipers, that use Fundy as a "fuel stop" (see Box 20.1).

Two species of cord grass dominate and delineate the marsh zones. On the low marsh, closer to the sea, saltmarsh cord grass (*Spartina alterniflora*) is the dominant or only species; on the high marsh, where tidal flooding may occur only three or four times a month, there is a succession of salt-loving plants, with saltmeadow cord grass (*Spartina patens*) predominating (Fig. 20.2). The seaward sides of the dikes are protected from erosion by *Puccinellia maritima*, a semi-salt-tolerant grass. In the Cumberland Basin the salt marshes are where 52% of primary productivity — the conversion of the sun's energy to growth — takes place (Gordon 1984). It is the salt marsh that supplies half the plant energy consumed by the zooplankton, invertebrates, fish, and birds that feed on the tidal flats and in the salt waters of the study area (Fig. 20.1); the other primary producers are phytoplankton (single-cell plants floating in the water) and benthic algae that flourish on the mudflats. In their energetic ebb and flow, tides transport thousands of tonnes of dead saltmarsh grass, so-called detritus, to the marine system where it forms a pool of nutrients (Gordon *et al.* 1985). In addition, the standing crop of cord grasses is an attractive food source for migratory waterfowl, in particular Canada Geese.

Previously the salt marsh that fed organic nutrients into the Bay of Fundy was much larger (it was 300 km^2 in the

BOX 20.1

A critical link

In July and August, migrating shorebirds funnel into the upper Bay of Fundy. Spectacular flights of tens of thousands of Semipalmated Sandpipers and other birds, their wings flashing white and dark as they whirl over their feeding grounds of mudflat and salt marsh, underscore the importance of this region to the autumn migration (Table 20.1). As many as 1.4 million shorebirds congregate in the upper Fundy. The Semipalmated Sandpiper is by far the most numerous species, constituting 95% of all shorebirds recorded.

Upper Fundy is a fuelling stop where shorebirds dramatically increase body weight in preparation for migration. From here, Semipalmated Sandpipers make a 4 300-km nonstop, transoceanic flight to South American wintering grounds. They show a marked preference for a few select sites along the Fundy coastline where the density of mudshrimp is greatest (Hicklin and Smith 1984).

The mudshrimp is a burrowing amphipod whose distribution in North America is restricted to the Bay of Fundy and Gulf of Maine (Peer *et al.* 1986). It feeds on detritus, supplied to the marine system from the neighbouring salt marsh by the ebb and flow of Fundy's great tides (Gordon *et al.* 1985).

Most shorebirds depend for their survival during migration upon a few widely spaced coastal and wetland habitats, like the Bay of Fundy. Separated by vast ecological barriers, such as forests or oceans, where landing or feeding is impossible (Environment Canada 1986; Myers *et al.* 1987), these sites are critical links in the shorebirds' annual cycle.

To protect all the key sites used by shorebirds on their extensive migrations, an informal consortium of conservation agencies, both public and private, created the Western Hemisphere Shorebird Reserve Network. The status of Shepody Bay as a wetland of international importance was recognized in 1987 when it was listed under an international agreement to protect wetlands, known as the Ramsar Convention, and it was made Canada's first Western Hemisphere Shorebird Reserve on August 8, 1987.

17th century and is now about 43 km^2); now the marine ecosystem receives fewer nutrients from this source. There is no way of knowing what impact this reduction may have had on marine productivity. Although the mudflats still support high densities of organisms, even greater numbers may have been present before dikes interrupted the detritus-based food chain.

Anecdotal sources offer at least an indirect hint of how the removal of salt-marsh habitat has affected bird populations. The name Tantramar is derived from an Acadian word, "tintamarre," meaning "a mighty uproar." It reportedly referred to the cries and wingbeats of vast flocks of waterfowl that stopped over to feed in the salt marshes on their spring and fall migrations. Though the area is still an important resting and feeding area for migrating waterfowl and shorebirds (see Table 20.1), it would be a gross exaggeration to describe the sound of even today's largest aggregations of waterfowl as "a mighty uproar." Extensive loss of habitat, combined with intensive hunting pressure (which continued until the adoption of the *Migratory Birds Convention Act* in 1917), has probably played a significant role in curtailing the size of the flocks that so impressed the early settlers.

The lowland that surrounds Shepody Bay and Cumberland Basin once formed the largest salt marsh in the Maritimes. The erection of dikes drastically altered the natural ecosystem, so that in its place is the largest block of diked wetlands (dikeland) in the region. Where dikes do not interrupt the tides' ebb and flow, the marsh continues to grow vertically at a rate of 30–45 cm per century, due to the combined effect of rising mean sea level and increasing tidal amplitude (Amos 1978). In most of the salt marshes today, the high tide line is marked by the sinuous signature of a dike.

The dikelands

The largest expanse of this landscape type is found in the Tantramar Marshes, where an area of close to 200 km^2, adjacent to Sackville, New Brunswick, has earned the title "world's largest hayfield." Though much of the dikeland is either hayland or pasture for grazing domestic cattle, wildlife persists. High numbers of meadow voles, in concert with abundant nesting habitat, enable the Tantramar Marshes to support what is likely the greatest population density of Northern Harriers (known to some as marsh hawks) in North America (Simmons *et al.* 1986).

Before the marshes were diked, the deepest, richest soils were deposited adjacent to the sea and along rivers (Fig. 20.2). Now water from the uplands tends to collect in the low-lying inland areas; so diking has resulted in a band of freshwater wetlands and shallow lakes, often surrounded by sphagnum bog (Fig. 20.4). In some of these more or less natural wetlands — for example, Tintamarre National Wildlife Area — artificial impoundments have been built to control water levels. These shallow, aquatic habitats host a large variety of wildlife, including muskrat and water birds.

A managed environment

It took the tides of Fundy more than 3 000 years to create the coastal wetlands of Chignecto; it took barely 300 years to convert those wetlands into a largely engineered environment, and, indeed, less than 30 to redo the engineering using modern machinery and methods.

TABLE 20.1

Maximum numbers of waterfowl and shorebirds counted in a single day in the upper Bay of Fundy

Species	Number	Season
Canada Goose	6 100	March–May
Brant	50	March–May
American Black Duck	1 550	September–November
Other dabblers[a]	2 200	September–November
Divers[b]	350	March–May
Sea ducks[c]	2 100	March–May
Semipalmated Plover	2 788	July–October
Black-bellied Plover	1 488	July–October
Greater Yellowlegs	154	July–October
Lesser Yellowlegs	1 356	July–October
Knots	1 447	July–October
White-rumped Sandpiper	707	July–October
Least Sandpiper	3 503	July–October
Dunlin	2 655	July–October
Short-billed Dowitcher	1 405	July–October
Semipalmated Sandpiper	456 355	July–October
Sanderling	1 150	July–October

[a] Mallard, Northern Pintail, Green-winged Teal, Blue-winged Teal, and American Wigeon.

[b] Ring-necked Duck, Bufflehead, scaups, goldeneyes, and mergansers.

[c] Oldsquaw, eiders, and scoters.

Source: Smith and Hicklin (1984).

Today, the Chignecto coastal wetlands and surrounding hills constitute a "managed" landscape. Within it, natural cycles and processes continue to operate, but they now do so in ways that are limited by, and subordinate to, human intervention. Without maintenance of the dikes, the area would revert to salt marsh.

Control of the tidal influence on major watercourses has greatly reduced the interaction between the marine ecosystem and the ecosystem of the diked marshes. For many years, important streams were inaccessible, because of dikes and aboiteaux, to the anadromous fish species that used to return annually to spawn. Recently, fisheries managers have been pressuring authorities to experiment with leaving control structures open during part of the tidal cycle. As a result, there is now a small run of sea-run trout on the Tantramar River.

Where the tide does not come up the rivers any more, tiding is no longer feasible. Tiding was key to a sustainable agriculture that lasted for more than 250 years with little or no other input of soil conditioners, such as lime or fertilizers. Although the dikeland soils are still among the most fertile in the Maritimes, many farmers no longer have the option of sustaining that fertility through the periodic application of tidal sediments. Management of dikelands for agriculture now includes the use of chemical fertilizers.

The freshwater lakes and bogs that formed at the inner limits of the dikelands have subsequently been altered: in some instances, by drainage and tiding, to create additional farmland; in others, by the creation of water level control structures to enhance nesting habitat for waterfowl. Both established waterfowl species — American Black Duck, Blue-winged Teal, Green-winged Teal, Ring-necked Duck — and waterfowl species attracted to the area by the artificial freshwater wetlands — Northern Pintail — nest and raise their young in this habitat. The controlled water level impoundments have also attracted marsh birds and waterfowl that were previously uncommon in the area, including Northern Shoveler, American Coot, and Black Tern, along with very high densities of Pied-billed Grebe. The improvement of freshwater nesting habitat has been a shared initiative of Ducks Unlimited Canada, a private international organization dedicated to preserving, developing, and maintaining waterfowl breeding habitat, and government, notably the Canadian Wildlife Service. Since 1965 the total area of freshwater wetland has increased substantially, by the conversion to freshwater wetlands of coastal dikeland areas that once were salt marsh.

A snapshot in time: two decades of change, 1961–81

For more than three centuries there has been varied, intensive land use on the upper Fundy wetlands. Environment Canada's (1990) study of a 2 137-km² study area in upper Fundy (see Fig. 20.1), including 1 870 km² of upland and 267 km² of dikeland, identified major changes in land use between 1961 and 1981. The study looked at the mix of current land uses (focusing primarily on agriculture, wildlife conservation,[1] and forestry[2]), potential new uses for the land, trends in the overall economy of the region, and the sustainability of land uses over the long term. The area was surveyed in 1961 and again in 1981 using aerial photography (Fig. 20.4). Environment Canada selected nine land-use classes (Table 20.2) and compared results for the two survey years using computer-based technology.

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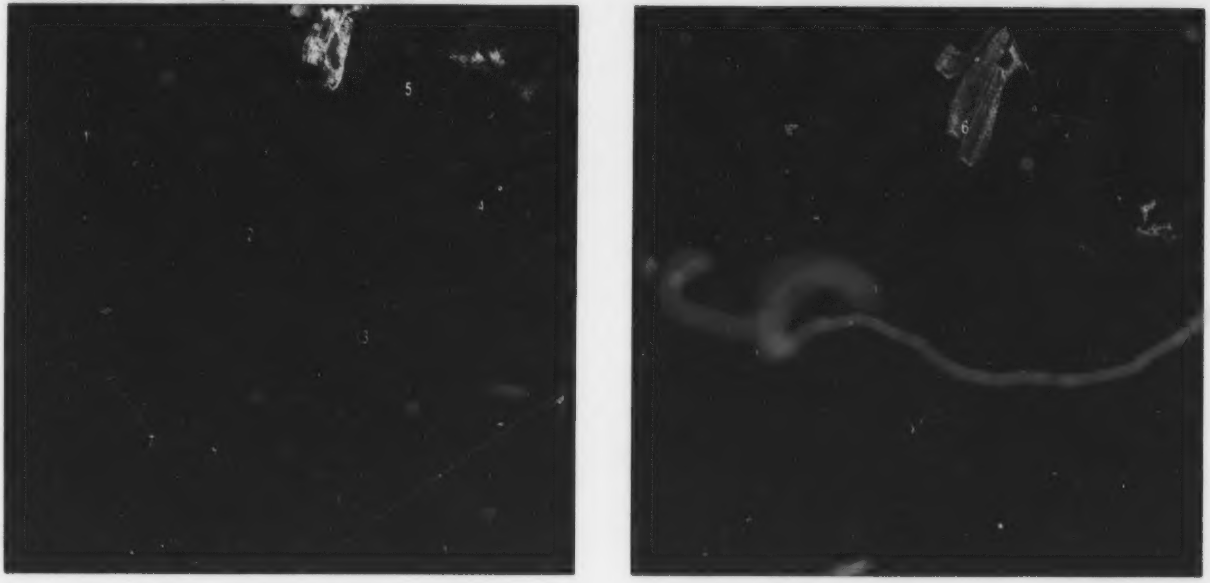
[1] The term "wildlife conservation" is used to describe those activities that maintain or increase natural habitats and their respective plant and animal communities.

[2] This chapter does not discuss the forestry changes.

FIGURE 20.4

Aerial photographs, taken in 1962 and 1982, show land-use changes on an area of dikeland (including freshwater wetlands) and upland

The Tantramar Marshes, just west of Jolicure, New Brunswick, have been modified greatly by people. Between 1962 and 1982, efforts to enhance wildlife habitat increased, and agricultural activities declined, on this relatively infertile section of the marsh.



	1962	1982
1.	Dikes[a]	Dikes[a]
2.	Domed peat bog	This bog has been recommended for protection under the International Biological Programme
3.	Natural wetland vegetation with little open water	Waterfowl habitat enhancement by ditching to increase amount of open water
4.	Natural wetland vegetation cover	The cattail mat has been cut to enhance habitat for waterfowl, muskrat, and other wildlife
5.	Pasture on upland	Pasture on upland
6.	Cropland on upland	Cropland on upland
7.	Original stream, bordered by a narrow strip of shrubs that provides protection for fish	Watercourse has been straightened and is no longer bordered by shrubs

---

[a] The dikes shown are for improvement of local freshwater habitat only. The nearest main dike protecting the area from tidal salt water is 6 km to the southwest.

Source: Amherst, Nova Scotia Land Registration and Information service.

TABLE 20.2

Description of land-use classes

Activity class	Description
Crops	Includes hay production, improved grasslands, and cereal and legume production
Grazing	Includes areas of unimproved grasslands
Other agriculture	Areas in commercial sod and low bush blueberry production
Natural areas	Areas with no agriculture, but with evidence of previous agricultural activity, such as fences and ditches; areas that showed no discernible signs of human activity when surveyed
Forestry	Areas with evidence of active cutting
Former forestry	Areas with no active cut, but with evidence of previous forestry activity, such as past cutting patterns and logging roads
Dwelling	Areas with residential structures
Conservation	Areas that support wildlife conservation activities, such as wetlands, impoundments, wildlife areas, reserves, and sanctuaries
Other activities	Industrial, communications, and transportation infrastructure

Source: Environment Canada, Inland Waters Directorate, Atlantic Region.

TABLE 20.3

The area of land that was formerly farmed[a] and the area that was used for agriculture during 1961 and 1981 for three agricultural capability classes[b]

	Former agriculture[a] (km^2)		Active agriculture (km^2)	
Capability class	1961	1981	1961	1981
Good capability	76	74	294	242
Poor capability	52	41	71	51
No capability	44	26	13	13

[a] Headings are based on classes in Table 20.2. "Former agriculture" is included in the natural areas class.

[b] Capability classes are based on Canada Land Inventory definitions (Canada Land Inventory 1972).

Source: Environment Canada (1990).

On the dikelands, over the 20 years, there was a major reduction in the area planted to hay, and a large area of abandoned agricultural land (included under natural areas in Table 20.2) was converted to other activities. At the same time, the dedication of land to wildlife conservation-related uses (e.g., wildlife reserves, waterfowl impoundments) increased significantly, indicating a shift from agriculture to conservation activities in some formerly productive agricultural dikeland areas (A. Hanson, Environment Canada, Canadian Wildlife Service, personal communication). On the uplands there was also a shift, in this instance away from the agriculture and natural areas categories, primarily towards forestry uses. Figure 20.5 depicts the relative shifts from one activity class to another in the course of 20 years. Among the many minor adjustments in land use, two major trends stand out: the decrease in agricultural activity and, at the same time, the gains made in the area of wildlife conservation. These land-use changes are reflected in the net revenues produced by the various activities in 1961 and, 20 years later, in 1981. Hay production continued to generate the greatest revenue on dikelands despite declines in the amount of land under production (Fig. 20.6). But the most significant *increases* were generated by sod farming and conservation of freshwater wetlands as habitat for wildlife.

The abandonment of farmland

The two surveys, in 1961 and 1981, indicate a significant decrease in agricultural activity across the study area (Environment Canada 1990). It is of interest to examine this trend more closely. Table 20.3 indicates that farm abandonment from 1961 to 1981 was not restricted to areas of poor soil capability, but was well distributed across the range of soil classes.

This suggests strongly that the trend was not solely a function of poor soil productivity or a high water table, but depended on a variety of socioeconomic factors. Market conditions, farm size, farm fragmentation, road access, changing social values, and farm family expectations all have played a role (Jackson and Maxwell 1971). Unlike the abandoned agricultural land, those areas that remained in active agriculture were predominantly situated on soils with the highest agricultural capabilities. Thus, although farm success is largely dependent on soil productivity and adequate drainage, soil productivity does not necessarily guarantee agricultural success. It is important to note that many of the factors that led to farm abandonment are in fact reversible. Future changes might make it profitable to revive agriculture in abandoned areas, assuming they had not been returned to the sea, converted to freshwater impoundments, paved over, or otherwise irreversibly altered.

Conservation of wildlife habitat

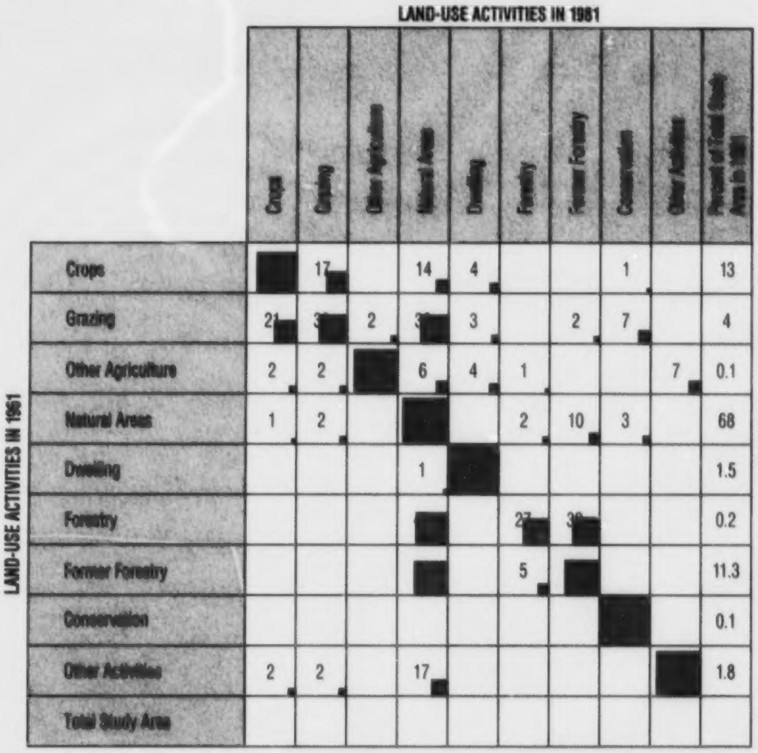
In the dikeland areas there was a marked shift from agriculture to wildlife conservation between 1961 and 1981. Agricultural land was converted to conservation, principally by the construction of freshwater impoundments to create habitat for waterfowl and other aquatic wildlife. Of the land newly converted to conservation purposes within the study area, 5% was derived from cropland, 17% from grazing land, 56% from abandoned agricultural lands, and 28% from areas where there was no perceived prior activity (Environment Canada 1990).

Conversion to conservation activities has been a stepwise process, with agricultural land being abandoned prior to development. This largely opportunistic activity indicates that, in general, wildlife management activities are not competing with agriculture for the same lands. Development of wetland habitat followed the recommendations of a study of previous landowners and land use in the Tantramar area (Jackson and Maxwell 1971). Idle lands formerly used for agriculture were identified as having considerable potential as waterfowl habitat. Government subsequently secured some of this land for conservation by purchasing it and giving it protected area status (Table 20.4).

FIGURE 20.6

Summary of the changes in land use on the 2 137-km² study area, between 1961 and 1981

The figure is designed to be read across rather than up and down. For example, it shows that of the area that was in crops in 1961, 64% remained in crops in 1981, whereas 17%, 14%, 4%, and 1% were converted to grazing land, natural areas, dwelling sites, and conservation areas, respectively.



LAND-USE ACTIVITIES IN 1981

LAND-USE ACTIVITIES IN 1961	Crops	Grazing	Other Agriculture	Natural Areas	Dwelling	Forestry	Former Forestry	Conservation	Other Activities	Percent of Total Study Area in 1961
Crops	■	17		14	4			1		13
Grazing	21	[illegible]	2	[illegible]	3		2	7		4
Other Agriculture	2	2	■	6	4	1			7	0.1
Natural Areas	1	2		■		2	10	3		68
Dwelling				1	■					1.5
Forestry				■		27	[illegible]			0.2
Former Forestry				■		5	■			11.3
Conservation								■		0.1
Other Activities	2	2		17					■	1.8
Total Study Area										

Source: Environment Canada (1990).

THE FUTURE OF UPPER FUNDY: SUSTAINABLE DEVELOPMENT AND THE TIDES OF CHANGE

Looking to the future of the upper Fundy region, there are indications that economic or social conditions might lead to competition between the two principal land-use sectors, namely agriculture and wildlife conservation, for certain prime parcels of land (Environment Canada 1990). How the land is used, in the future, will depend on the economic returns from current land uses and resource management activities, and on the ability of the two competing sectors to adopt cooperative strategies, such as multiple land use.

Economic basis of agricultural activities

One of the noticeable trends in agricultural activity in upper Fundy, as elsewhere, has been towards larger farm units and greater capital intensity in production. The land-use data show that the amount of farmland in production in 1981 was less than 60% of what it was in 1961, but the actual farm population in the study area was only about 10% of what it was in 1961 (Stokoe *et al.* 1989). In other words, not only was less land in production, fewer people were being employed on the land base.

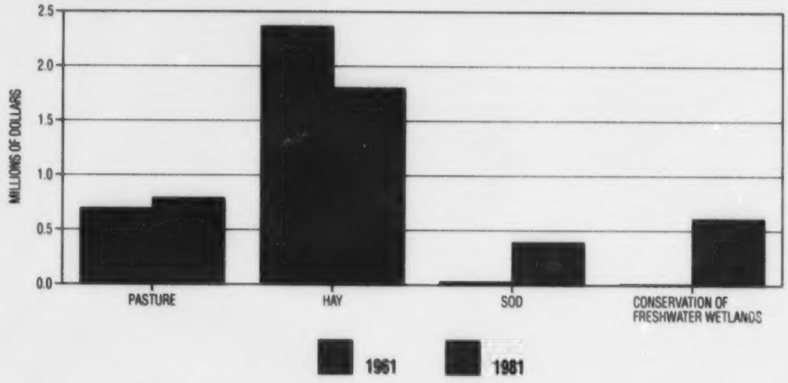
As the postwar trend away from the small, mixed, family farm as a mainstay of the Maritime rural economy accelerated in the upper Fundy region during the 1950s and 1960s, the upland properties (which were less fertile, more acidic, and consequently less productive than dikelands) were generally the first to be abandoned. In 1981, only 19% of the upland with potential for agriculture was so employed, compared to 79% of the dikeland (Environment Canada 1990). Except for the recent increase in the cultivation of wild blueberries, there has been little indication that the upland areas are likely to return to agricultural production in the near future. The same observation holds true for abandoned dikeland.

Furthermore, land-use analysis and a review of economic factors influencing land use show that, given present market conditions, the amount of land in agricultural production will likely decrease (Environment Canada 1990). Although there have been some increases in prices and markets for hay, profit margins are still far short of those realized in the early 1920s. It is unlikely that hay prices will increase or markets expand enough to encourage farmers to

[illegible]

Comparison of net revenues in 1961 and 1981 generated by various land-use activities on dikeland in the upper Bay of Fundy

The amounts are in 1988 dollars.



Source: Environment Canada (1990).

TABLE 20.4

Existing and proposed protected areas in the upper Bay of Fundy region

Name	Year established	Area (km²)	Designation
Shepody	1980	9.8	National Wildlife Area
Shepody Bay	1988	102	Ramsar site and Western Hemisphere Shorebird Reserve
Tintamarre	1977	19.9	National Wildlife Area
Chignecto	1982	10.9	National Wildlife Area and Ramsar site
Missaguash Marsh	1982	24.0	Provincial Game Management Area
The Rocks	1958	0.2	Provincial Park
Ducks Unlimited Canada sites	various dates	68	freshwater impoundments
—	proposed	1.93	2 candidate Ecological Reserves in New Brunswick

Source: Stokoe *et al.* (1989).

put substantially more land into hay production. The markets for beef, dairy, and sheep production in the region are limited mainly to Nova Scotia and New Brunswick and are currently static (Stokoe *et al.* 1989). Expansion of beef, hog, or grain production into new markets is unlikely, because of direct competition with producers in central and western Canada, where physical conditions are more favourable. Sod production alone represents a profitable new initiative well-suited to dikeland soils. The practice is similar to mining the soil, as the top 0.5–1.25 cm of soil is stripped away at each harvest; however, the great depth of marshland soils and the local nature of the market make sod production sustainable (Stokoe *et al.* 1989), with the only limiting factor being the depth of soil above the water table.

A variety of subsidies are granted to Canadian farmers to allow them to compete in a heavily subsidized world market. All of these subsidies have the effect of making the amount of land of all types dedicated to agriculture greater than it otherwise would be. With regard to dikelands, government subsidies for drainage and dike maintenance as well as for landforming may make dikeland farming more attractive than upland agriculture. On the other hand, subsidies for fertilizers may have a contrary tendency to encourage agricultural use of less fertile uplands.

In general, existing agricultural subsidies promote particular practices that tend to distort the way farming is conducted compared to the most efficient and sustainable methods (Stokoe *et al.* 1989). For example, subsidies for chemical fertilizers can have negative impacts on soil microbes, thus affecting the sustainability of the agricultural activity (Stokoe *et al.* 1989). Overall, the major effect of agricultural subsidies is to keep more land, and more dikeland in particular, in agriculture, and thereby significantly reduce the amount of land available for other uses such as wildlife conservation.

In the context of subsidies and sustainability, it should be noted that although public monies (a form of subsidy) were used for the original purchase of conservation areas, annual operating expenses are covered by private donations to Ducks Unlimited Canada. Public subsidy for maintenance of the dike system currently protects agricultural land, freshwater wetlands, and the transportation, residential, and communications infrastructure.

Sustainability of wildlife conservation activities

Upper Fundy contains many habitats and ecosystems within its boundaries. To date, concerted efforts have been made to conserve critical habitats, such as the shorebird staging area at Marys Point, vestigial salt marshes (John Lusbys Marsh), and the Amherst Point Bird Sanctuary (see Box 20.2), as well as low-lying areas on the dikeland that could be relatively easily restored to productive wildlife habitat, such as Minudie Marsh (Fig. 20.3).

Although many of the lowland sites on the dikelands have been improved, they continue to require considerable upkeep. The layer of organic deposits (Fig. 20.2) promotes an extensive development of floating mats of cattail after flooding. Such floating mats are undesirable for waterfowl conservation purposes. Their dense growth severely limits the amount of open water, which then must be established by costly, labour-intensive mat-cutting procedures. Because of this, and because most suitable low-lying sites have already been "improved" as waterfowl habitat, there is a desire at present to locate new projects on abandoned agricultural lands that are close to the dikes. There are inherent advantages, as there are for agriculture, to locating freshwater ponds on fertile, well-drained mineral soils with little or no organic layer. Also, were freshwater impoundments sited closer to the coast and river banks, waterfowl would have easier access to the salt marsh and mudflats, which would likely result in more sustained use. Furthermore, by employing the old technique of tiding — allowing salt water to enter the impoundment on occasion — cattail growth could be controlled and soil fertility renewed. For these reasons, abandoned agricultural lands closer to the coast and river banks and diked tidal streams are considered to have prime conservation potential. This zone, of course, represents the very locations that were highly productive wetlands in their original state, until they were converted, through human intervention, into hayfields.

BOX 20.2

Evolution of a bird sanctuary

The Amherst Point Bird Sanctuary is a tapestry of wetland types. In the 300 years since European settlement, the Amherst Point marshlands have come full circle from salt marsh to homestead to wetland again, although now more of the wetlands are freshwater and maintained for the purpose of wildlife conservation.

The reclaimed salt marshes and upland fields were farmed continuously from 1761 until the 1940s. The area was also the site of short-lived industrial activity. Between 1905 and 1912, the Maritime Gypsum Company mined the rich gypsum deposits in the area, and the railway bed that linked the mines to the loading docks on Cumberland Basin is now a nature trail.

Local townspeople had long used "the Glen" for recreational purposes. Their lobby to preserve the wildlife values of the areas resulted, in 1947, in the Government of Canada establishing the sanctuary with the agreement of the landowners. The federal government acquired the lands in the early 1970s as part of a national habitat protection program and designated them as a component of the Chignecto National Wildlife Area, which also included the 600-ha John Lusbys Marsh, the largest remaining salt marsh in the upper Bay of Fundy.

Today, the sanctuary encompasses the most diverse wetland habitat in Nova Scotia, including natural ponds and bogs, flooded freshwater impoundments, wooded uplands, and abandoned agricultural fields. This rich and diverse mosaic of habitats and the strategic location of the sanctuary on a major migratory route have attracted more than 200 species of birds, including many rare and unusual water birds.

A complete picture of the area's conservation potential would include all wetlands, whether marine (e.g., salt marsh 39 km^2, mudflats 159 km^2) or freshwater (e.g., lakes, existing impoundments, cattail marshes). In total, 440 km^2 of the study area (136 km^2 on the dikelands) were identified as having high wildlife conservation value (Environment Canada 1990). Though the conservation potential of these diverse habitats has not been systematically addressed, economic development strategies based on nature-related tourism are currently being implemented by communities in the upper Fundy. The Amherst Point Bird Sanctuary, created in the 1970s for recreational use, attracts large numbers of bird watchers to its nature trails. Nonconsumptive uses of wildlife and natural ecosystems are increasingly seen as activities that can generate sustained profits in the service sector of the economy. This recognition has led to creation of a waterfowl park in Sackville, New Brunswick, and sponsorship of an annual waterfowl festival to attract visitors and focus attention on the conservation values of the area. Building on these successes, Cumberland County, Nova Scotia, has stated in its five-year action plan for Amherst and area that wildfowl marshes will be developed as major tourist attractions in cooperation with the provincial government and Ducks Unlimited Canada (Cumberland Futures Committee 1987).

Healthy waterfowl populations attract many visitors — both bird watchers and hunters — to the region. As indicated by Table 20.5, significant net gains have been made in the numbers of breeding waterfowl in the New Brunswick – Nova Scotia border region (Whitman 1984). Whereas brood production has remained constant in the natural freshwater marshes, the increases are due to improvement of habitat in the area, with the waterfowl reaching their highest concentrations on artificial impoundments.

The region is not experiencing the full increase in waterfowl populations that the habitat improvements make possible, because the improved areas are readily accessible to hunters and are not protected by special regulations. Consequently, when hunters congregate on these managed areas during the hunting season, they can inflict high losses on locally reared waterfowl. Special regulations for managed marshes, for example to limit the number of hunters and set rules about distribution of blinds, would enhance survival of local populations of American Black Ducks, especially during the critical early days of the season when they are most vulnerable (Parker, in press).

Competition or cooperation: multiple land use

Both conservation and agricultural activities require highly productive natural systems, which, in upper Fundy, are supported by the deep inorganic sediments deposited by the tides. Dikeland has been called "a reserve of energy in the form of fertility" (Nova Scotia Department of Agriculture and Marketing 1987). Because of the inherent richness of the soil and the large historical investment in dikes and drainage to protect that resource, the agricultural community is intensely interested in preserving the land base for future use, whether or not it is economic to farm the dikeland currently. At the same time, the conservation sector is no longer interested in developing large impoundments on poorer low-lying dikeland soils, as in the past, but has a desire to develop smaller cells within blocks of dikeland closer to the coast.

The fact that conservation lands have been created from agriculturally inactive areas supports the observation that there has been only limited direct competition between these dominant land users to date. The continuing trend of land abandonment, and the large reserve of existing abandoned land, suggest that there will be little competition for the land base in the foreseeable future (A. Smith, Environment Canada, Canadian Wildlife Service, personal communication). Land-capability analysis indicates, however, that once existing inactive fertile land near the dikes (20 km^2 in study area) has been developed, more intensive competition between agriculture and conservation can be expected on the dikeland (Environment Canada 1990).

In that event, there will be a strong need for cooperative land-use planning as a way of sharing this valuable resource. Multiple land use is one option for avoiding competition and, at the same time, optimizing the capability of dikelands. The multi-use approach was first recommended in the early 1970s and has formed a basis for development since that time (Jackson and Maxwell 1971). For example, on a given block of marshland, the slightly higher and better-drained portions might be maintained for agriculture, whereas the lower sections and drainage systems would be managed for waterfowl. Wildlife habitats could be fenced off, except for places made accessible for beef stock watering. This multi-use approach would permit the area's potential for waterfowl use to be developed without affecting the greater part of the idle but improved agricultural land.

The alternative to the multi-use approach is the complete loss of one of the resources in a given location. However, any change from single use to multiple use must take into account the historical and continuing investment in dikeland and the cultures and communities associated with it.

There are examples of complementary use of the land base in the region. Since the early 1970s, wild rice has been grown in freshwater impoundments in the Nova Scotia – New Brunswick border region, where the high fertility of the marine silts renders them well-suited to the heavy nutrient demands of the plant. The rice has produced commercial crops while at the same time attracting waterfowl to the region (F. Payne, Nova Scotia Department of Lands and Forests, personal communication).

Wetlands are efficient filters. As such, one of the potential benefits of wetlands is to provide some degree of sewage treatment. The town of Hillsborough, New Brunswick, population approximately 1 700, situated on the tidal Petitcodiac River, has an artificial stabilization pond on the marshland for sewage treatment. The system was installed at a savings of at least 50% compared to a conventional sewage treatment plant. The stabilization pond has also proved to be a productive habitat for American Black Ducks (Stokoe *et al.* 1989).

TABLE 20.5

Total breeding pairs of five major waterfowl species observed in the New Brunswick – Nova Scotia border region, 1954–60 and 1978–84

Species	1954	1955	1956	1957	1958	1959	1960	7-yr. ave.	1978	1979	1980	1981	1982	1983	1984	7-yr. ave.
American Black Duck	41	31	19	110	18	20	8	35	83	55	31	36	32	47	51	48
Green-winged Teal	1	1	8	7	0	2	0	3	18	11	6	5	3	1	15	8
Blue-winged Teal	0	0	7	2	4	3	5	3	16	14	4	11	5	5	12	10
Ring-necked Duck	2	4	6	1	3	5	0	3	26	17	11	17	27	17	19	19
Northern Pintail	3	7	10	12	2	4	1	6	9	14	8	6	0	5	4	7
Total	**47**	**43**	**50**	**132**	**27**	**39**	**14**	**50**	**152**	**111**	**60**	**75**	**67**	**75**	**101**	**92**

Source: Whitman (1984).

The importance of natural areas

Portions of the upper Fundy area are not currently being exploited for any direct social or economic benefit. Far from being wastelands, natural areas play an important, albeit passive, role in resource conservation.

This role is especially important in a region like the upper Bay of Fundy, which people have changed profoundly over the past three centuries. Lands that have never been actively developed and those that have not been used for a long time are the very ones where there is some hope for the survival of native ecosystems. Indeed, the biodiversity of the salt marsh, the freshwater wetland, the upland forest, and the other natural landscapes of the area can best be preserved through human inactivity. Taken collectively, they provide breeding and rearing habitat for well over a hundred species of native birds, as well as a wide variety of mammals, fish, and invertebrates. In addition, many plant species, some of them rare, can survive only in locations where there is little or no human disturbance (see also Chapter 7).

Natural areas are integral to ecosystem health. The salt marshes play a major ecological role by supplying organic carbon to the marine system (Gordon *et al.* 1985). The enormous value of the mudflats and salt marshes as feeding and staging areas for migratory waterfowl and shorebirds is well known. Less widely understood, perhaps, is the importance of the lakes and sphagnum bogs as freshwater reservoirs at the inland margin of the dikelands.

BOX 20.3

Fundy tidal power

Since the turn of the century, the very high tides typical of the upper Bay of Fundy have attracted the attention of those interested in utilizing this vast reservoir of potential energy. Escalating oil prices in the 1970s led to a reexamination of the economic viability of Fundy tidal power development, as well as a thorough evaluation of the environmental consequences of the proposed megaproject (Gordon 1984).

Erecting a dam across a major inlet of the upper Bay of Fundy (e.g., Shepody Bay or Cumberland Basin) would have far-reaching oceanographic consequences, extending as far south as Boston. All environmental effects would stem from fundamental changes to the tidal regime. Tidal ranges seaward of a tidal dam would be accentuated; however, behind the dam — within the so-called headpond — the opposite would be true.

Changes in tidal range would have significant ecological impacts on the production of life in upper Fundy. Within the headpond, primary production of benthic diatoms (algae) on the mudflats and cord grass production on the salt marshes would decrease by 65% and 35%, respectively. As the water cleared in the headpond, this loss might be partially replaced by the production of phytoplankton, which is now limited due to high turbidity in the water. Overall productivity might not be reduced, but major shifts in relative abundances of organisms could influence predators higher in the marine food chain. In particular, the ability of migratory species, such as waterfowl, shorebirds, and fish, to utilize the food sources traditional to the area could be affected (Gordon 1984).

Sedimentation, such as that observed on the Petitcodiac River after the erection of the causeway, could reduce the availability of invertebrates, which in turn would affect the foraging distributions, densities, feeding success, rates of fat deposition, and length of stay of shorebirds in Fundy. Loss of one-half or more of the mudflat area within the headpond also could lead to increased feeding competition (Smith and Hicklin 1984). As well, high fish mortalities, from 20 to 50% on a single passage through the STRAFLO (straight flow) turbine, have been observed at the Annapolis Tidal Power Station. Such losses may pose an unacceptably high risk to recovering North Atlantic stocks of American shad and Atlantic salmon (Thurston 1990).

Though tidal power is nonpolluting in the traditional sense, in determining whether tidal power represents the most sustainable use of the region's resources, the loss of internationally important habitat for waterfowl and shorebirds and turbine-related fish mortalities would have to be major considerations in the decision-making process (see also Chapter 4).

External and local factors affecting land use in upper Fundy

External factors might well have a deciding effect on land use in the upper Bay of Fundy. A trend in forest practices on the uplands towards increased size and number of clear-cuts will remove the habitat of some species of upland wildlife and may increase runoff into the dikeland. Global warming might favour the production of cereals, legumes, and other crops on dikelands, and thus provide impetus to agriculture in future. At the same time, drier conditions in the central parts of the continent might cause wetlands there to dry up. In such an event, the wetlands in eastern Canada could become relatively more important in maintaining continental wildlife populations. Any rise in mean sea level due to global warming would increase the cost of maintenance of dikes, which protect both agricultural and current freshwater conservation areas (Stokoe *et al.* 1989). A demand for energy for the regional electrical grid or for export, or public pressure for alternatives to nuclear or geothermal electrical production, could renew interest in the development of Fundy tidal power, which would affect the regional ecology and economy (see Box 20.3).

Although local point sources of contamination from industries and urban centres do not appear to be having negative impacts on wildlife populations at present, over time and in combination with diffuse sources, such as agricultural runoff and runoff associated with the increasing area of forest clear-cuts, as well as pollution from residences and vehicles, some impact on environmental quality and land use may occur.

CONCLUSIONS

The upper Fundy wetlands have undergone drastic alteration through the intervention of people and technology, in particular the technology of dike-building, which was brought to the area by the Acadians more than three centuries ago. Fully 90% of the original salt marsh was eventually cut off from the influence of the tides for agricultural purposes. In the last 25 years, large areas of abandoned agricultural land have been converted into productive freshwater wetlands.

Though agriculture continues to be the dominant activity on dikelands, the increasing importance of conservation accurately reflects economic and social trends. For the region as a whole, land uses will depend upon the economic rate of return gained from these uses. It is unlikely in the near future that there will be increases in demand and prices for agricultural products that can be produced on the dikelands. On the other hand, increased interest in environmental quality will likely augment the relative attractiveness of the region for recreation.

The area's geographic location on a major transportation corridor, between Nova Scotia and eastern Canada, and its landscape and wildlife resources make it an ideal recreational setting. Expansion of the tourist industry would coincide with a general shift from an agriculture-based economy to a service-based economy. However, such a transition would have to be sensitive to the communities and culture that have been dependent on the dikelands since the area was first settled and preserve sufficient lands for future agricultural use.

The rich wetlands of upper Fundy have served many purposes for 300 years — as farmland, globally significant wildlife habitat, and hunting ground — and they are likely to continue to do so in future. There has always been, and always will be, potential for competition between the two activities of agriculture and conservation. A multiple-use approach is the best means of sharing the land resource in the region. Ultimately, a high diversity of land uses provides environmental and economic resilience in the face of external and unpredictable stresses.

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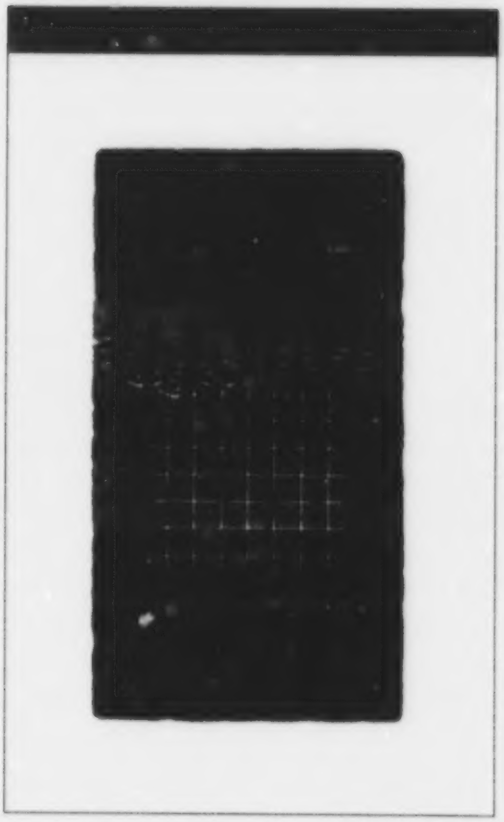

PART
IV
CURRENT ISSUES

21

LIQUID
LIQUID
(PCB)
SOLID WASTE

COURTESY OF MIKE SCHULTZ, OTTAWA

HIGHLIGHTS

Since the end of World War II, chemical manufacturing has expanded dramatically, and with it the release of human-made substances into the environment.

■

Probably the best-known category of toxic contaminants is chlorinated organic compounds, including DDT and PCBs, which have been found in organisms at all levels of the food chain, throughout the world.

■

Fish and birds — particularly birds' eggs — are the most commonly used monitors of toxic contaminants. The most consistent trend observed has been a significant decline in the levels of DDT and derivative compounds in all the areas surveyed. PCBs have also declined in many areas, although not always significantly.

■

Although dramatic accidents involving undesired releases of large quantities of harmful chemicals have occurred, less dramatic, but equally serious, releases during normal manufacture, use, and disposal have been common and still occur.

■

For most human beings, food is probably the most significant avenue of exposure to toxic chemicals. Natives, and others whose diet includes large amounts of fish and wildfowl in which dangerous levels of toxic substances may have accumulated through bioconcentration, may face a greater risk of exposure to toxic chemicals than other groups in the population.

■

Most Canadians are now less exposed to toxic contaminants than they were in the 1960s and 1970s. However, many of the toxic chemicals that have been the focus of concern in recent years remain in the environment and could continue to pose a hazard to both wildlife and human health for many years to come.

■

The concept of cradle-to-grave management has significantly shaped both legislative and voluntary initiatives for controlling toxic chemicals.

■

Under the Canadian Environmental Protection Act, a Priority Substances List has been established that identifies those chemicals that need to be dealt with most urgently. Assessments of 44 chemicals are to be completed by 1994.

■

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> **The rapidity of change and the speed with which new situations are created follow the impetuous and heedless pace of man rather than the deliberate pace of nature.... The chemicals to which life is asked to make its adjustment are no longer merely the calcium and silica and copper and all the rest of the minerals washed out of the rocks and carried in rivers to the sea; they are the synthetic creations of man's inventive mind, brewed in his laboratories, and having no counterparts in nature.**
>
> — Rachel Carson (1962)

INTRODUCTION

In 1948, Swiss chemist Paul Mueller received a Nobel Prize for his discovery of the insecticidal properties of DDT. The award acknowledged one of the major medical achievements of our era. Used against disease-carrying insects, DDT brought about a rapid and phenomenal reduction in the incidence of deadly diseases such as malaria, yellow fever, and typhus. Used to protect crops and trees against insect pests, it promised new levels of productivity and security to farmers and foresters. It appeared to be another wonder chemical, an invaluable tool against the twin scourges of disease and famine.

Within a decade, however, evidence began to accumulate that DDT was harmful not only to insects but also to many other living things. In areas where it had been used extensively, fish and birds began to show signs of deformity and reproductive failure. Later studies suggested that the chemical might also be linked to human health problems. With the publication of Rachel Carson's *Silent spring* in 1962, the safety of DDT became a major public issue. By the early 1970s, evidence of the harmful effects of DDT had become clear and irrefutable. As a result, many countries, including Canada, placed partial or complete bans on its use.

The story of DDT is a classic example of the dilemma posed by chemicals in modern society. Chemicals can be both highly beneficial and highly dangerous. In seeking to reap the abundant benefits they offer, people may also inadvertently run the risk of doing serious harm to the environment and to human health. The problem that faces Canada, as a society that is highly dependent on chemicals, is how to realize the benefits of these substances while avoiding the damage they may cause or, at least, reducing the risk of such damage to acceptable levels. A key element in the solution to this problem is the proper management of chemicals.

The benefits derived from the use of chemicals are extensive and impressive. Modern chemical technology has saved lives, reduced human suffering, diminished the threat of famine, increased economic productivity, and added enormously to the convenience and quality of everyday life. Medicines, pesticides, fertilizers, preservatives, explosives, photographic materials, synthetic fibres, household cleansers, plastics, miracle adhesives, cosmetics — these and thousands of other products, from the essential to the trivial, rely on chemicals. In fact, chemicals are used by virtually every industrial sector and in virtually every home in Canada. It is almost impossible to overstate their importance and their ubiquity.

Since its beginnings in the 19th century, chemical manufacturing has been a key sector of most western industrial economies, but it has expanded dramatically since the end of the Second World War. In Canada, the chemical and chemical products industry ranks fifth among Canadian manufacturing sectors. In 1988, the value of shipments amounted to $21.9 billion, or 7.5% of all shipments of manufactured goods (Canadian Chemical Producers' Association 1990*a*).

However, especially since the end of the Second World War, these benefits have been offset to some degree by increasing evidence of chemical hazards. Much of this evidence has been dramatic: the decimation of the Japanese village of Minamata by mercury poisoning in the 1950s, the widespread incidence of birth defects caused by thalidomide in the 1960s, and the death of more than 4 000 people in Bhopal, India, in 1984, as a result of a methyl isocyanate leak at a chemical plant (see Box 21.1). At the same time, evidence of mortality, reproductive failure, and mutations in wildlife populations has also heightened public awareness of a more subtle problem, the pervasiveness and persistence of low-level toxic contaminants in the environment.

Chemicals, of course, can pose many threats to the environment when their harmful properties are not understood or fully respected. This chapter discusses only toxic chemicals — that is, chemicals that are poisonous, causing death or injury to living things as a result of immediate exposure or leading to cancer, organ damage, genetic mutation, birth defects, or other biological harm as a result of long-term exposure. The chapter focuses on the nature of these chemicals and their effects, as well as on how to minimize their dangers through effective toxic chemical management.

THE NATURE OF TOXIC CHEMICALS

Toxic chemicals are not a new problem. In fact, extremely poisonous substances, such as cyanide and chlorine, have been used as industrial chemicals since the 19th century. These substances are typical of those that have traditionally been thought of as toxic chemicals — their toxicity is immediate and direct, and a short exposure to high dosages of them is enough to cause sudden injury or death. However, the obvious toxicity of these chemicals has made their management relatively straightforward, because it is clear that they must be handled with great caution.

Some 30–40 years ago, however, the problem of toxic chemicals took a new and troubling turn, when it became apparent that many chemicals — even some previously thought to be relatively benign — could be toxic even in very small quantities if exposure to them was sufficiently prolonged. In the case of some chemicals, it was found that daily doses that could be measured only in parts per billion, or even parts per trillion, could have harmful biological effects over a long period. Because environmental concentrations of these substances tend to be extremely low, relative to concentrations of other pollutants, they are often referred to as microcontaminants.

Typical of such materials is the large family of chlorinated organic compounds, of which DDT and PCBs are perhaps the best-known members. Chlorinated organic compounds, or organochlorines, were widely used as

BOX 21.1

Major toxic chemical incidents

1956	Widespread mercury poisoning was discovered in the Japanese fishing village of Minamata. Over the next 20 years, 107 deaths and several hundred cases involving serious sublethal effects, including brain damage and birth defects, were reported. The outbreak resulted from eating fish and shellfish contaminated by mercury effluent from a nearby chemical plant.
1960s	The drug thalidomide was withdrawn from the market in several countries after its use by pregnant women had been shown to be instrumental in causing birth deformities.
1968	A mass poisoning incident took place in Yusho, Japan, after cooking oil was contaminated with PCBs, furans, and polychlorinated quaterphenyls. The victims developed chloracne, roughened and thickened skin on the hands and feet, darkened nails and gums, swollen, inflamed eyelids, sweating of the palms, and sensory changes (including weakness, itching, and hearing and sight deficiencies). Most, but not all, effects disappeared over a 10-year period.
Early 1970s	A mysterious disease began killing horses at three riding stables in central and eastern Missouri. Before the epidemic was over, more than 60 horses died, one six-year-old child was hospitalized, and several persons became ill. Dozens of pets and hundreds of birds were killed. After three years of investigation, the cause of the epidemic was traced to a tank of industrial wastes contaminated with 2,3,7,8-TCDD, trichlorophenol, and PCBs. Salvage oil from the tank had been used as a dust control spray in several horse arenas and stables, as well as on parking lots and streets. In 1982, all 2 400 residents of Times Beach, one of the communities affected, were moved permanently to other centres after dangerously high dioxin levels were detected in the town's soil and streets.
1976	An explosion at a chemical factory showered the town of Seveso, Italy, with dioxins and furans, killing thousands of birds and small animals. Among the humans affected, the principal symptom was chloracne, with approximately 190 cases reported.
1978	A health emergency was declared near Niagara Falls, New York, when it was discovered that highly toxic chemical wastes from the nearby Love Canal disposal site were seeping into residential backyards. Eventually, 1 030 households were evacuated.
1979	Cooking oil contaminated with PCBs, furans, and polychlorinated quaterphenyls was once again the cause of mass food poisoning, this time in Yu-Cheng, Taiwan. Effects were similar to those observed in the 1968 Yusho incident. Higher levels of infant mortality and of delays and deficits in mental development were observed among children who had been exposed in the womb.
1979	Mercury discharges from a [illegible] paper plant forced the closing of the commercial and recreational [illegible] on the Wabigoon–English river system in northern Ontario, causing considerable damage to the economic and social stability of local Amerindian bands.
1979	Chlorine leaking from damaged tank cars forced the evacuation of 200 000 people after a train carrying toxic chemicals was derailed in Mississauga, Ontario.
1984	An accidental discharge of deadly methyl isocyanate from a chemical plant in Bhopal, India, left 4 000 people dead and thousands of others with lingering and incapacitating illnesses.
1988	A fire at a PCB storage site forced the evacuation of residents from the town of Saint-Basile-le-Grand near Montreal.

FIGURE 21.1

Bioconcentration of toxic contaminants in the food chain

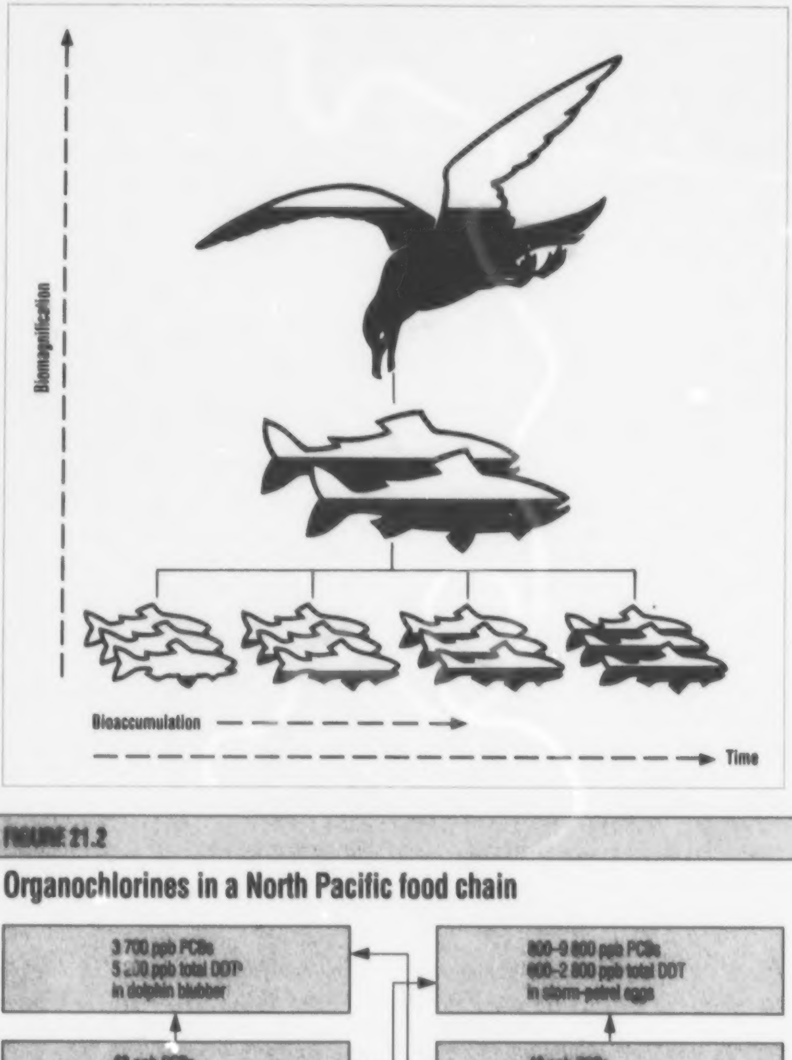
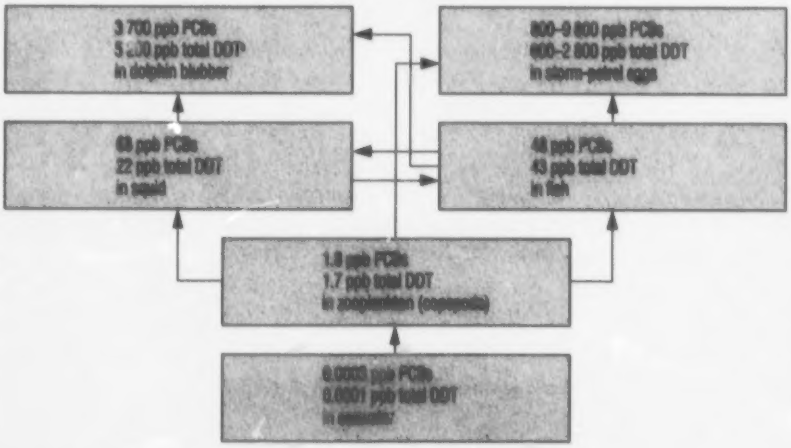

Biomagnification
Bioaccumulation
Time

FIGURE 21.2

Organochlorines in a North Pacific food chain


3 700 ppb PCBs
5 200 ppb total DDT[a]
in dolphin blubber
800–9 800 ppb PCBs
600–2 800 ppb total DDT
in storm-petrel eggs
68 ppb PCBs
22 ppb total DDT
in squid
48 ppb PCBs
43 ppb total DDT
in fish
1.8 ppb PCBs
1.7 ppb total DDT
in zooplankton (copepods)
0.0003 ppb PCBs
0.0001 ppb total DDT
in seawater

[a] Total DDT=DDD+DDE+DDT.

Source: Noble (1990), based on data from Tanabe *et al.* (1984) and Noble and Elliott (1986).

pesticides and in a broad range of industrial applications, particularly during the 1950s and 1960s. Although only trace quantities of these chemicals remained in the air and water, they nevertheless had a dramatic impact on many wildlife populations, especially predatory birds, causing a variety of effects that ranged from death to reproductive failure and genetic defects. Accidents involving the exposure of humans and other animals to larger doses of these chemicals also showed that they posed a serious risk to human health.

In addition to the chlorinated organic compounds, a variety of other chemical groups give rise to toxic microcontaminants in the environment. Heavy metals, such as lead and mercury, are prominent among these, as are a number of hydrocarbons, particularly polycyclic aromatic hydrocarbons (PAHs) and volatile organic compounds (VOCs). Boxes 21.2–21.6 provide information on several major groups of toxic chemicals.

The mechanisms of microtoxicity

How can apparently insignificant quantities of these chemicals exert such formidable effects? Apart from their intrinsic toxic properties, these substances often have certain other characteristics that, over time, greatly enhance their capacity to do biological damage.

One of the most important of these characteristics is their chemical stability, which allows them to persist in the environment for long periods without breaking down into less harmful byproducts. When absorbed or ingested by a living organism, many (though not all) of these substances gradually accumulate in its tissues. Organochlorines, for example, tend to accumulate in fat because they are highly fat-soluble. Through this process — known as bioaccumulation — contaminant levels within an organism may gradually build up to harmful levels.

Organisms may also pass their accumulation of contaminants on to other creatures that feed on them. This process is known as biomagnification because, as the contaminants move upwards through the food chain, their concentration increases. Together, the two processes are sometimes referred to as bioconcentration, and they can account for a quite astonishing intensification of contaminant levels in living tissue (Fig. 21.1).

Studies of marine food chains, for example, show relatively low concentrations of contaminants in the zooplankton at the lower end of the chain but higher levels in the fish that feed on them. Birds and marine mammals such as dolphins that feed on the fish show still higher levels of contaminants. Although concentrations of a substance such as DDT may be barely detectable in seawater, those in a seabird high in the food chain may be several million times higher as a result of the combined effects of bioaccumulation and biomagnification (Fig. 21.2).

Species differ in their ability to metabolize various contaminants and thus in the extent to which they accumulate these substances. Organochlorines, for example, do not appear to accumulate as readily in mussels and crustaceans as they do in fish. Beluga (white whales), on the other hand, build up very large concentrations of these compounds. An analysis of blubber from belugas in the St. Lawrence estuary showed PCB concentrations of 65 000 ppb and DDT concentrations of 70 000–100 000 ppb. Seabirds from the same area, although occupying much the same level in the food chain, showed much lower concentrations of these chemicals — 5 000–25 000 ppb for PCBs and 1 000–10 000 ppb for DDT (Masse *et al.* 1986; Noble and Elliott 1986).

Some chemicals undergo transformations in the environment that make them much more biologically active or that ease their entry into the food chain. Liquid mercury, for example, is relatively harmless to higher organisms because it passes through the digestive tract without being absorbed. However, when transformed by bacterial action into an organic form such as methylmercury, it is easily assimilated and, being chemically stable, can accumulate in tissue and increase in concentration as it passes through the food chain. Similarly, most of the harmful effects associated with DDT are, in fact, caused by DDE, one of its principal breakdown products.

BOX 21.2

Toxic chemicals: chlorinated organic pesticides

Introduced in the 1940s, chlorinated organic pesticides were widely used in Canada in the 1950s and 1960s to control agricultural and forest pests. DDT is the best-known member of this group, which includes a number of other pesticides, such as dieldrin, heptachlor, chlordane, HCH (hexachlorocyclohexane), mirex, and toxaphene, as well as the fungicide HCB (hexachlorobenzene). Most of these chemicals are highly persistent.

During the 1960s, chronic exposure to organochlorine pesticide residues was recognized as a key factor in eggshell thinning, reproductive failure, and population decline in birds and other wildlife species. These effects and fears of a possible threat to human health led to the imposition of tight restrictions on the use of these chemicals and the banning of some of them during the 1970s and 1980s.

As of 1990, only a small number of chlorinated organic pesticides were registered for use in Canada. These included methoxychlor, endosulfan, lindane, chlordane, heptachlor, and dicofol. Chlordane, used in termite control, is the most persistent. It can be applied only by licensed operators with provincial permits. Heptachlor is used only in nurseries. Methoxychlor, endosulfan, and lindane are relatively nonpersistent.

In North America and western Europe, chlorinated organic pesticides have largely been replaced by less persistent organophosphate and pyrethroid compounds. They continue to be used in many Third World countries. There has, however, been a recent decline in their use globally. Recent efforts to limit the use of chemical pesticides have focused on the development of microbial pesticides, such as *Bacillus thuringiensis* (see Chapter 10).

Some chemicals that may be harmless individually can also act together to create health or ecosystem problems because of the interaction of their effects. These chemicals are said to interact synergistically: in other words, their combined effects are greater than the sum of their individual effects. Because of the sheer number of chemicals that organisms are exposed to in a polluted environment, interactions of this kind are a distinct possibility.

The tip of the iceberg?

At present, public concern about toxic chemicals has been focused on a relatively small number of substances, perhaps a few hundred at most, and many of these are closely related members of only a few chemical families. However, more than 35 000 chemicals are used commercially in Canada alone, and almost twice that number are used worldwide. Just how many of these represent a serious environmental or health hazard is not clear. Because many concerns about specific toxic chemicals came to light only after unanticipated environmental damage or adverse health effects had already occurred, there is a danger that more unpleasant surprises of this kind could be in store.

In addition, the vast majority of the chemicals now in use are synthetic compounds. Although both natural and synthetic chemicals can be toxic, nature has evolved balances and controls that limit the effects of natural toxins on the environment. Cobra venom, for example, may be lethal to individuals, but it does not constitute an ecological hazard. Generally, it is only when natural chemicals are present in abnormally high concentrations or in altered forms that their effects disrupt ecological processes. Synthetic chemicals, however, are substances that are new to

BOX 21.3

Toxic chemicals: PCBs

Versatile and highly stable, PCB compounds have been used since 1929 in a wide variety of applications. The primary use in Canada has been as insulators and coolants in electrical transformers and capacitors. In these applications, the PCBs are enclosed and can enter the environment only via leaks and spills. They have also been used in products such as wall coverings, paints, and pesticides, which permit their easy release to the environment. PCBs are extremely persistent, easily dispersed, and accumulate readily in the food chain. Once in the environment, they are not easily removed.

Sustained high-level exposure to PCBs, as in the Yusho incident of 1968, has been associated with a number of effects, the most common being chloracne, a persistent acne-like skin condition. Other effects include eye discharge, swelling of the upper eyelids, hyperpigmentation of the nails and skin, numbness of the limbs, weakness, muscle spasms, chronic bronchitis, and decreased birth weight and head circumference in newborns. There is also a possible link between long-term high-level exposure and liver cancer.

Studies of the children of women who regularly consumed PCB-contaminated fish during pregnancy suggest that long-term prenatal exposure to lower levels of PCBs can lead to slight reductions in mental development.

There are more than 200 different forms of PCBs, and most commercial PCBs are complex mixtures of a large number of these. The toxicity of these forms varies considerably. PCBs are known to contain furan contaminants; these are toxic at very low concentrations.

The manufacture, importation, and most nonelectrical uses of PCBs were banned in Canada in 1977, but about 25 000 t remain in use or in storage. It is estimated that another 15 000 t have escaped into the environment over the years, primarily as a result of inadequate disposal, especially in landfill sites. A program is now under way to destroy the remaining PCBs using high-temperature incinerators. However, because PCBs now in the environment will remain for many years, Health and Welfare Canada has established exposure limits for various foods and is continuing to monitor PCB levels in air and water as well as in individual food items.

the environment. They may not necessarily fit into one of the many cycles of decay and regeneration that maintain balances among natural substances. Moreover, living things may not be able to adapt to these new chemicals because they have not evolved mechanisms to deal with their biological effects. The release of synthetic chemicals to the environment, therefore, involves risks that cannot be taken lightly.

TOXIC CHEMICALS IN THE ENVIRONMENT

Once in the environment, toxic chemicals can be difficult to control. Because they are commonly released from a wide variety of sources and are easily dispersed to areas far from where they originated, the contamination they cause is frequently widespread. Moreover, persistent chemicals are not easily removed or broken down by natural or human processes. Having entered the environment, they tend to remain there for long periods of time.

Sources

Toxic chemicals can enter the air in many different ways. The smokestacks of factories, generating stations, waste incinerators, and smelters discharge sulphur dioxide, nitrogen oxides, carbon monoxide, hydrocarbons, and other combustion products into the atmosphere, sometimes along with other toxic substances such as heavy metals, dioxins, and furans. Motor vehicles and the fuels they use are another major source of airborne contaminants, including carbon monoxide, hydrocarbons, and lead (where leaded gasoline is still used), as well as the nitrogen oxides and VOCs that contribute to the formation of ground-level ozone. Pesticides and herbicides, because they are usually applied as a fine spray or mist, enter the atmosphere with particular ease. Volatile chemicals, such as paints, solvents, and fuels, often enter the air through evaporation. Accidental releases, on both small and large scales, also add to the mix of toxic chemicals in the atmosphere.

In heavily populated areas, toxic chemicals are often released into bodies of water through a variety of point sources such as industrial discharge pipes and municipal sewage and storm sewer outlets. Frequently, municipal sewage also contains industrial effluents. In Ontario, for example, some 300 industrial locations discharge directly into rivers and lakes, but at least 12 000 more dump their wastes into municipal sewage systems that cannot adequately treat toxic chemicals. As a result, it is estimated that as much toxic pollution enters Ontario waters from sewage treatment plants as from direct industrial discharge (Ontario Ministry of the Environment 1986, 1991). It is not only the large volume of such wastes that makes them environmentally dangerous but also the fact that, in total, they may contain significant amounts of almost every chemical made or used by humankind.

Non-point sources such as rainwater runoff also add to the toxic burden of our waters. Pesticides and chemicals that have been deposited on the ground from the air are commonly washed into rivers and lakes in this way. In addition, a substantial amount of toxic material can enter water bodies, especially those with large surface areas, directly from the air. More than 90% of the PCBs, DDT, and lead in Lake Superior, for example, come from atmospheric deposition (Strachan and Eisenreich 1988).

Serious contamination can also occur as a result of toxic chemicals leaking into the water table from hazardous waste that has been buried in dumps and landfills. One of the most notorious examples is the Niagara River, which has been heavily polluted as a result of leakage from hazardous waste sites on the American side. An estimated 315 kg of toxic chemicals enter its waters daily from several large U.S. sites located within 5 km of the river (Government of Canada 1991).

Leakage from hazardous wastes can also contaminate soils. Such was the case in 1978, when industrial solvents, pesticides, and other toxic chemicals from the Love Canal, one of the Niagara region disposal sites, seeped into the soils of a residential area, ultimately forcing the evacuation of 1 030 households.

Much of the concern over toxic contamination in the environment has centred on the Great Lakes (see Chapter 18). There are some 36 million people within the Great Lakes drainage basin, as well as 28 cities with populations greater than 50 000 and more than 13 000 manufacturing and industrial plants. Most of these are concentrated in the southern part of the region. In such a heavily urbanized and industrialized area, there is inevitably a heavy use of chemical products. According to the International Joint Commission (1987), the waters of the Great Lakes contain at least 362 chemical contaminants, including toxic metals, pesticides, PCBs, industrial feedstocks, and dioxins.

Dispersal

Toxic chemicals can be carried long distances by winds and water currents and by living things that have absorbed them. If these substances are highly persistent, they can spread far from their points of origin and accumulate, possibly in harmful concentrations, even in places that are remote from any major source of toxic pollution. The tissues of wildlife in the Canadian Arctic, for example, contain traces of PCBs and pesticides originating far to the south in the populous industrial and agricultural regions of Europe, Asia, and North America (Environment Canada 1989) (see Chapter 15). Although concentrations are considerably lower than those found in areas such as the Great Lakes basin, the fact that they are found at all in the Arctic makes it clear that there are no safe havens from toxic contamination.

The mobility of toxic pollutants also means that pollution from local sources can be augmented by contaminants originating in other areas. A situation of this kind occurs in the St. Lawrence estuary, which is affected not only by pollution from industry, agriculture, and shipping along the St. Lawrence itself, but also by contaminants from the Great Lakes basin. The organochlorine pesticide mirex, for example, reaches the estuary from the Great Lakes rather than from local sources.

A further consequence is that national or regional bans on the use of specific chemicals cannot be completely effective in reducing contamination from them if the same substances remain in use in other parts of the world. Thus, even though pesticides containing hexachlorocyclohexane (HCH), one of the less persistent organochlorines, were phased out of use in Canada in the 1970s, high concentrations of this chemical were found in the eggs of Ancient Murrelets in British Columbia's Hecate Strait in the mid-1980s (Elliott *et al.* 1989). It is thought that the HCH originated in Asia, where pesticides containing it are still in use.

Storage and recycling

Many toxic chemicals, such as organochlorines, PAHs, and heavy metals, adhere readily to the surfaces of fine particles. This not only facilitates their transport through air and water but also results in their accumulation in soils and aquatic sediments. As sediments build up, the toxic chemicals in them are immobilized. Shorter-lived chemicals in these sediments may break down into

BOX 21.4

Toxic chemicals: dioxins and furans

Polychlorinated dibenzodioxins (PCDDs) and dibenzofurans (PCDFs) originate as by-products and contaminants of chlorinated organic compounds. The principal sources in Canada today are chlorophenol wood treatment agents, phenoxy herbicides, effluents from pulp and paper mills using chlorine bleaching processes, tobacco smoke, and older municipal incinerators and other sources of incomplete combustion. Furans are also present in PCBs.

There are 75 varieties of dioxins and 135 varieties of furans. The toxicity of these varies substantially, but some are very toxic. The most potent dioxin, 2,3,7,8-TCDD, can have carcinogenic and reproductive effects on rats at concentrations of only 10 ppt.

The most common effect of high-level exposure to dioxins and furans is chloracne. Other effects include skin thickening and discolouration, impairment of the immune system, liver damage, and sensory and behavioural effects. Mammals exposed to prolonged low-level dosages show many of the same symptoms, as well as cancer, reproductive effects, and birth defects. Although 2,3,7,8-TCDD is an extremely powerful animal carcinogen, epidemiological studies of humans have not demonstrated a conclusive link with cancer. These investigations, however, have been complicated by the difficulty of isolating the effects of dioxins and furans from those of other chemicals.

Dioxins and furans have been declared toxic substances under the *Canadian Environmental Protection Act*. Although Canadians are exposed to very low levels of these substances, steps are being taken to reduce emissions from both pulp and paper mills using chlorine bleaching and older incinerators. Chemical sources of dioxins and furans, such as PCBs and chlorophenols, are closely regulated, and changes in production processes have resulted in a decrease in dioxin and furan contaminants released by the production and use of chlorophenols and phenoxy herbicides.

harmless by-products, but the most persistent chemicals may remain there for centuries. If the sediments remain undisturbed, small amounts of these chemicals may again find their way into the water column; however, if the sediments are disturbed drastically — usually by dredging — large amounts of toxic substances may be liberated to accumulate in the food chain or circulate through the water and air. Because they have been banked in this way, some chemicals could remain a danger long after their production has ended.

Exposure

Humans can be exposed to toxic chemicals through skin contact as well as through the air they breathe, the food they eat, and the water they drink. Small children have commonly been exposed to dangerous substances by ingesting contaminated soil. For most human beings, food is probably the most significant avenue of exposure, particularly food such as fish or gamebirds in which dangerous levels of toxic substances may have accumulated through bioconcentration. Natives, residents of fishing communities, hunters, and others whose diet includes large amounts of fish and wildfowl may face a greater risk of exposure to toxic chemicals than other groups in the population. Individuals living in some highly industrialized areas may also be more exposed to airborne contaminants. A recent study of exposure routes for people living in the Great Lakes basin indicated that 80–90% of their intake of chlorinated organic chemicals comes from food, 5–10% comes from the air, and less than 1% comes from water (Newhook 1988; Birmingham *et al.* 1989).

Factory workers who make or use toxic chemicals have occasionally been exposed to high levels of certain chemicals. The emergence of health problems among these workers has often acted as an early warning of the toxicity of these substances. Chemicals whose toxicity has come to light in this way include asbestos, arsenic, mercury, PCBs, benzene, and vinyl chloride.

It has been estimated that 9% of cancer deaths in Canada are work-related

BOX 21.5

Toxic chemicals: heavy metals

In certain forms and in sufficient concentrations, heavy metals such as cadmium, lead, tin, and mercury can be toxic to living organisms. Natural environmental levels of these metals are usually too low to do much biological damage, but human activities have greatly increased the chance of exposure to harmful concentrations. In recent years, concern has focused primarily on the hazards of lead and mercury.

Lead

Lead can enter the environment from many sources: the mining and smelting of lead-bearing ores and metals, lead plumbing and solder, paints and ceramic glazes, and the careless disposal of lead–zinc batteries in landfill sites. Until the phasing out of leaded gasoline in 1990, motor fuels containing tetraethyl lead were the major contributor of lead to the environment in Canada. In 1980, these fuels accounted for 60% of the lead emissions from human-made sources in this country.

Lead poisoning can lead to anemia, brain damage, and loss of kidney function. Children are particularly susceptible.

Lead releases are being decreased through the use of emission-reducing technologies and the phasing out of some applications, particularly in paints and motor fuels. These efforts are expected to reduce annual lead emissions in Canada from more than 14 000 t in 1978 to less than 4 000 t in 1995 (Fig. 21.B1).

Mercury

Mercury and mercury compounds are naturally present throughout the environment — in rocks, soils, plants, animals, water, and air — but human activities have intensified their concentrations in some locations and parts of the environment. The metal has been widely used in electrical applications, in thermometers and barometers, in paints, in seed treatment, in chemical production, and in dental fillings.

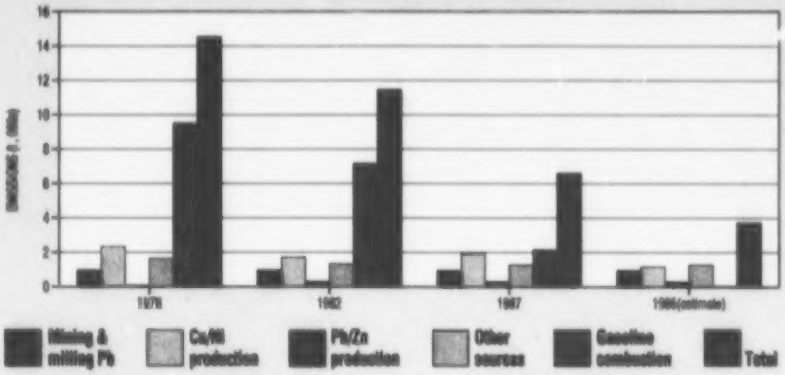
Mercury is highly toxic, and death can occur from the ingestion of only a few milligrams of an organic mercury compound or from the inhalation of air containing elevated levels of mercury vapour. Long-term exposure to low levels of mercury can cause neurological damage, kidney damage, and severe weight loss. Unborn children are particularly sensitive to the effects of mercury.

Organic mercury compounds can also inhibit photosynthesis and growth in phytoplankton and have caused death and reproductive failure in birds. High levels of these compounds can be found in fish that feed in mercury-contaminated waters. Many fish-eating mammals, such as mink, marten, otters, and seals, appear to be highly susceptible to mercury poisoning.

Sources of mercury releases to the environment include the recovery of metals, the burning of coal, the use of paint, and the production of chlorine and caustic soda. Mercury is released from soil and vegetation in areas flooded by new dams. Since the early 1970s, the amount of mercury released to the environment has decreased substantially. Control and process improvements, closer regulation of emissions and effluent discharges, control of mercury waste from solid waste disposal sites, and the replacement of mercury with alternative materials have all contributed to the decline. The use of organic mercury compounds for seed treatment is now banned, for example, and the use of mercury in chlorine and caustic soda production has largely been phased out — 16 plants have either shut down or been converted since 1973.

[illegible]

Distribution of lead emissions in Canada, 1978–95



Source: Hilborn and Still (1990).

BOX 21.6

Toxic chemicals: hydrocarbons

A number of hydrocarbon compounds are toxic or are considered potentially toxic. Two of particular concern are benzene and a large family of benzene derivatives known as polycyclic aromatic hydrocarbons (PAHs).

Approximately 700 000 t of benzene are produced in Canada each year, mostly for use in the production of other chemicals. Some of this escapes to the environment through industrial effluent, spills, and leakage from landfill sites and storage tanks. However, most of the benzene entering the environment comes from the burning of motor fuels. Tobacco smoke and the incomplete combustion of refuse in municipal incinerators also account for significant releases. PAHs are primarily a by-product of incomplete combustion from gasoline and diesel engines and from the burning of wood and coal. They are commonly found in soot, coal tar, various types of oil, and petroleum distillates.

Although short-term exposure to very high concentrations of benzene can be lethal, benzene is primarily of concern as a source of irritants in smog and as a carcinogen. Similarly, PAHs are of concern because some of them are carcinogenic. Fish taken from PAH-contaminated waters show an increased incidence of liver and other tumours.

Both benzene and PAHs are among the first group of chemicals on the Priority Substances List to be studied. The results of these assessments will be available by 1994.

(Miller 1984). However, most major industries have developed comprehensive procedures for medical surveillance and monitoring of occupational health, and there is now a complex regulatory framework in place across Canada to assess and control workplace exposures. Injuries due to chemical exposure have always been a relatively small component of all workplace injuries, and they are continuing to decline (Statistics Canada, various dates).

Homes and offices are a common source of exposure to toxic materials. Buildings in which the exchange of air between indoors and outdoors has been severely reduced by the use of insulation and other energy-saving measures may have poor indoor air quality.

A recent study of VOCs in indoor and outdoor environments in Toronto measured concentrations of more than 130 compounds. It concluded that "the indoor air quality appeared to be two to five times worse than the outdoor air quality" (Bell *et al.* 1991) (see Chapter 13).

Common sources of indoor pollutants include paints, cleaners, plastics, cosmetics, building materials, upholstery, cigarette smoke, aerosol sprays, solvents, and recently dry-cleaned fabrics. Even showers can produce a small amount of chloroform from the vaporization of chlorinated water. During the 1970s and early 1980s, eye, nose, and throat irritations, skin rashes, and other symptoms were linked to the use of urea-formaldehyde foam insulation (UFFI) in houses. Sealed highrise office buildings with internally circulating ventilation systems have also been identified as a factor in a variety of health problems.

TRENDS

Monitoring the levels of microcontaminants in the environment can be a difficult exercise, partly because the concentrations that have to be measured are often extremely low. Levels of microcontaminants in air and water, for example, are usually in the parts per billion range or less. Indeed, it is only since the early 1980s that chemists have had the technology necessary to measure such minuscule quantities, and the procedures needed to obtain reliable results are complex, time-consuming, and expensive.

For that reason, scientists often prefer to monitor the presence of microcontaminants in those parts of the environment where they accumulate, in aquatic sediments and in living matter such as algae, plankton, fish, birds, and other forms of wildlife. Fish and birds are the most commonly used monitors of microcontaminants. Being high in the food chain, they contain larger, more easily measured quantities of bioconcentrated contaminants than lower life forms. They also give some indication of the biological effects of these substances.

Care is needed, however, in interpreting the results of these studies. Birds and fish are mobile and often migratory, and so are their prey. Consequently, some of the contaminants detected in them may have come from areas other than those in which specimens were collected. In addition, species vary both in their capacity to absorb different chemicals and in their responses to them. High accumulations and adverse effects in one species do not necessarily mean that other species will be similarly affected. Nevertheless, evidence of this kind does indicate that the chemicals detected are biologically active and should be a cause for concern.

Birds' eggs have proved to be particularly useful in the monitoring of contaminants. Because each species' eggs are more or less standard in size and composition, samples from different locations can be easily compared. Moreover, the migratory and feeding patterns of the birds used as monitors are well known, and it is therefore possible for researchers to account for remote as well as local sources of contamination.

The Canadian Wildlife Service has monitored chemicals in the eggs of certain seabird species on the Atlantic coast since 1968. A similar program has been in place on the Pacific coast since 1985, although less systematic sampling has been done there since 1970. Continuing studies of contaminants in fish and birds' eggs in the Great Lakes date back to the late 1970s. The data collected in these and other programs provide some indication of trends in the concentrations of toxic contaminants in the environment.

Organochlorines have been closely monitored in a number of studies. The most consistent trend observed in these has been a significant decline in the levels of DDT and derivative compounds such as DDE in all of the areas surveyed. PCBs have also declined in many areas, although not always as significantly. However, for most of the other organochlorines that have been monitored — specifically, the pesticide dieldrin, the fungicide hexachlorobenzene (HCB), and the pesticide derivatives oxychlordane and heptachlor epoxide — there has been considerable local variation and no clear trend in levels.

Increasingly tight restrictions and, in some cases, bans on the use of these substances have been in place in Canada and the United States since the 1970s, but they continue to enter the food chain from a variety of sources, including atmospheric transport from countries where they are still used, leaching from soils and hazardous waste dumps, and the disturbance of sediments. Figures 21.3 and 21.4 show the results of a 15-year survey of levels of PCBs and organochlorine pesticides in seabird eggs at sites in the Gulf of St. Lawrence and the Strait of Georgia. Although there are differences in trends from site to site, the patterns shown here are fairly representative of the general tendencies observed in these monitoring programs.

Industrial discharges of mercury have also decreased substantially as its use in pulp and paper production and in the manufacture of chlorine and caustic soda has been phased out. These reductions have been reflected in a downward trend in the levels of mercury detected in various species of fish. This trend can be seen in Figure 21.5, which shows a rapid decline in average mercury concentrations in walleye in Lake St. Clair during the early 1970s. After reaching a plateau in the late 1970s, concentrations declined further during the 1980s, levelling off at approximately a quarter of the 1970 value. The decline in mercury levels has permitted the reopening of some Great Lakes commercial fisheries that had been closed in the 1970s.

During the 1970s and 1980s, the amount of lead entering the environment also declined, largely as a result of the phasing out of leaded motor fuels, which were by far the largest single source of lead emissions in the early 1970s. The decrease in the amount of lead present in the atmosphere has been quite dramatic: between 1974 and 1989, average ambient air levels of lead particles declined by 93% (see Chapter 2). However, lead pollution remains a concern in some localities because of lead-contaminated soils or atmospheric emissions from plants recycling lead scrap.

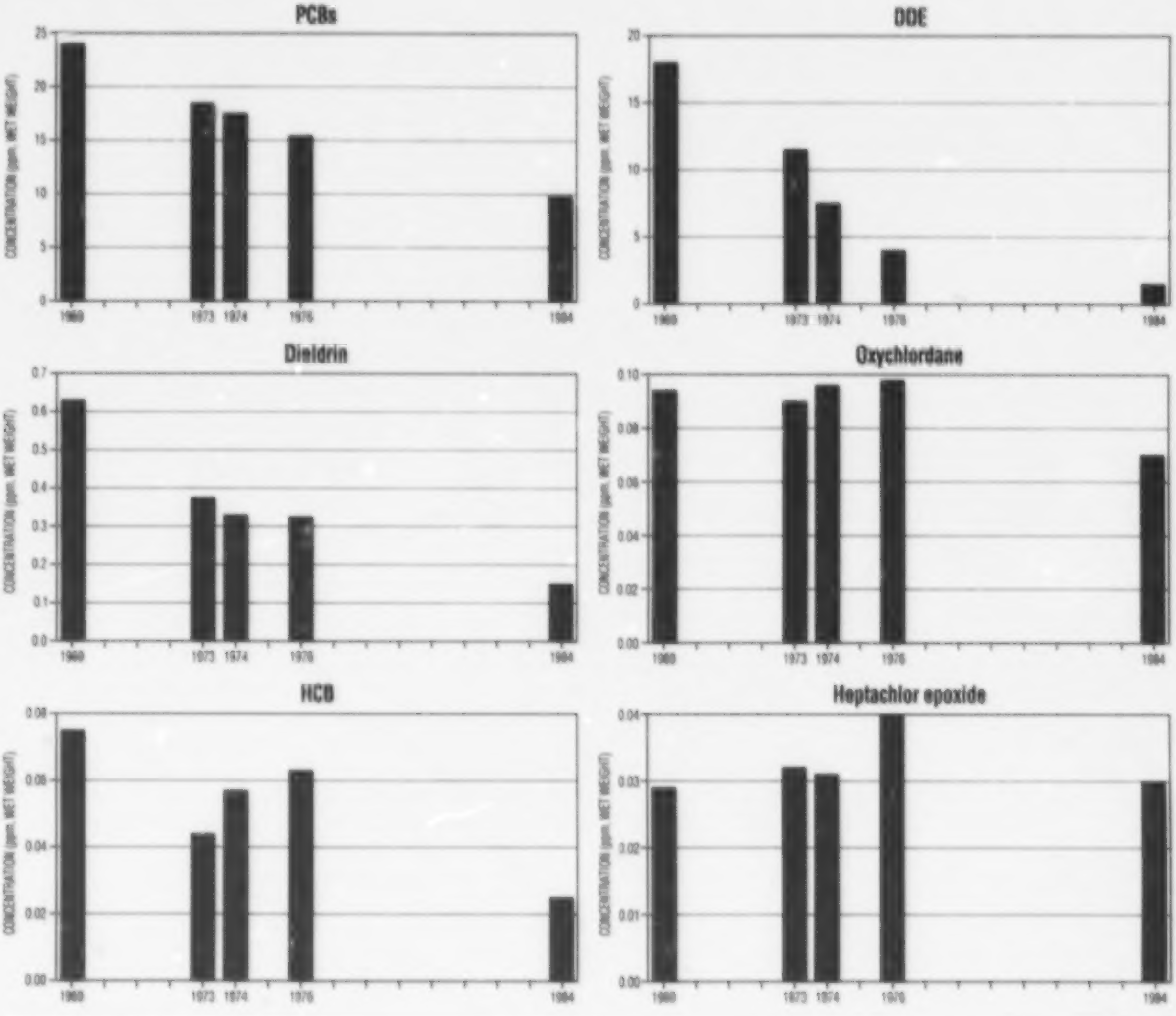
Some decrease in the quantity of dioxins and furans entering the environment has probably occurred as a result of the reduced usage of chemicals, such as chlorophenols and PCBs, that contain these substances as contaminants. At the same time, the dioxin and furan content of chemicals still in use, such as the herbicide 2,4-D, has been more strictly regulated. However, small but significant quantities of dioxins and furans continue to be released from a variety of sources, most notably pulp and paper mills using chlorine bleaching processes, municipal incinerators using outdated control technology, and hazardous waste dumps. As a result, there are no clear trends in environmental levels of these compounds.

Studies of dioxin concentrations in Herring Gull eggs in the Lake Ontario area, undertaken in the 1970s and 1980s, showed a quite spectacular drop in levels of 2,3,7,8-TCDD, the most toxic form of dioxin (Fig. 21.6). These results have been attributed to the closing of a chlorophenol plant on the Niagara River in the early 1970s. However, during the same period, dioxin concentrations in Lake Ontario lake trout varied but showed no obvious trend (Fig. 21.7), and it is assumed that these levels reflect continuing contamination from hazardous waste sites along the Niagara River. On the west coast, elevated levels of dioxins and furans have been found in shellfish and birds' eggs in the vicinity of pulp mills using chlorine bleaching. These results have led to the closing of some shellfish fisheries and to the issuing of health advisories for others.

In general, the evidence suggests that most Canadians are now less exposed to toxic contaminants than they were in the 1960s and 1970s. However, many of the toxic chemicals that have been the focus of concern in recent years remain in the environment and could continue to pose a hazard to both wildlife and human health for many years to come. Controlling and, if possible,

FIGURE 21.3

Changes in contaminant levels in fresh eggs of Northern Gannets at Bonaventure Island in the Gulf of St. Lawrence, 1969–84



Source: Noble (1990).

reducing these toxic residues will be an important component of any scheme for the management of toxic chemicals.

In addition, there are thousands of other toxic chemicals entering the environment that have been neither monitored nor regulated. Exactly what effects some of these may be having on the environment we do not know for sure. Another catastrophe on the scale of Minamata seems unlikely, but it is nevertheless a possibility. Thus, although we appear to be winning the initial skirmish in the fight to control toxic chemicals, the battle is far from over.

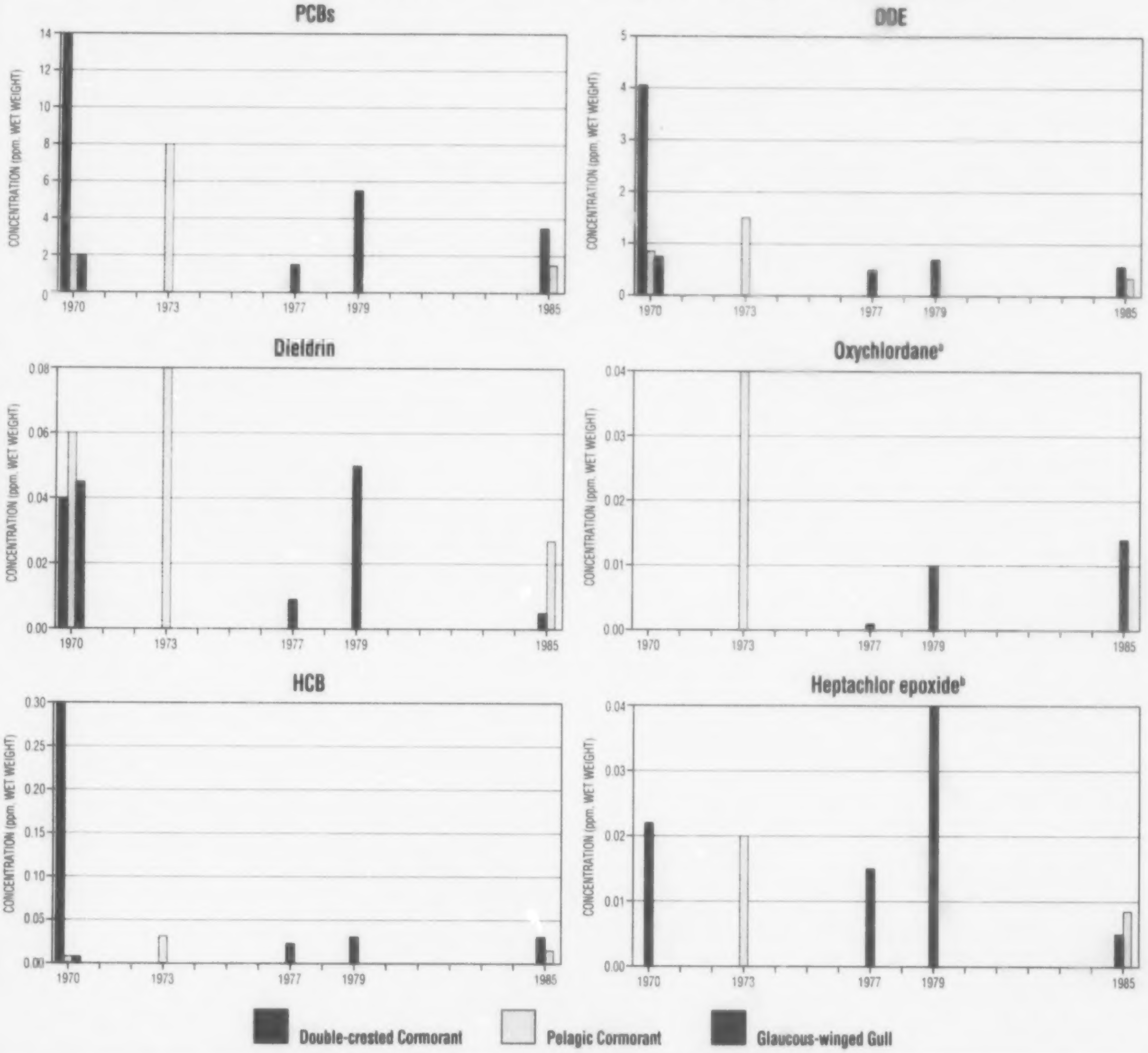
ASSESSING THE RISK

When is a substance toxic?

A toxic substance, simply defined, is one that causes some adverse biological effect in a living organism. However, establishing the toxicity of a substance is not always as straightforward an exercise as this simple definition would suggest. In fact, the line of demarcation between a toxic and a nontoxic substance can be very faint. In other words, toxicity is not always an absolute characteristic of a particular substance; in many cases, it is a relative condition that depends on particular environmental circumstances.

FIGURE 21.4

Changes in contaminant levels in eggs of seabirds breeding in the Strait of Georgia, 1970–85



[a] Prior to 1973, eggs were not analyzed for oxychlordane.

[b] None of the 1970 samples was analyzed for heptachlor epoxide.

Source: Noble (1990).

Toxicity is partly dependent upon concentration. Indeed, almost any substance can be toxic to an organism if it is exposed to too much of it. Furthermore, different organisms, and even individuals, respond in different ways to toxic materials. A substance that is highly toxic to one species may be only moderately toxic to another or not toxic at all to a third. Table 21.1, for example, shows the variation in median lethal doses (i.e., the single dose required to kill half a group of test animals) among a variety of species for the highly toxic dioxin 2,3,7,8-TCDD. Even for two closely related species, such as the hamster and the rat, the lethal dose can vary by a factor of more than 200. In determining the risk that a certain quantity of toxic material may present, therefore, we have to remember that it could be defined differently for each species we are trying to protect.

The toxicity of a substance may also depend on its behaviour in the environ-

ment. Is it likely to be transformed, like mercury and DDT, into a more biologically active form? Or does it break down rapidly from a toxic form to a nontoxic form? Does it accumulate in the environment in such a way as to increase the exposure of organisms to it? The chlorinated organic chemicals now present in Lake Ontario drinking water, for example, are not considered a hazard to human health. However, the same chemicals in some Lake Ontario fish are, simply because the levels of chemicals in the fish are much higher as a result of bioconcentration.

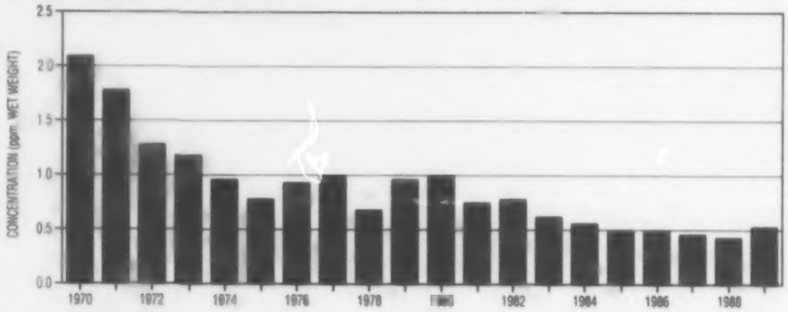
In the case of complex mixtures of chemicals, it is also extremely difficult to link toxic effects to one component specifically. There are more than 200 different forms (congeners) of PCBs, for example. Commercial PCB mixtures usually consist of a number of these, along with trace quantities of as many as 75 different forms of furan contaminants. We know from laboratory studies that the toxicity of these individual PCB and furan congeners varies considerably, but in cases of PCB exposure it has not been possible to determine unequivocally whether the observed effects were caused by PCBs or furans, let alone which were responsible for specific symptoms.

Nevertheless, in spite of the very great difficulty of establishing clearly the toxic effects of some chemicals, it is essential that we know as much as possible about the probable toxicity of every chemical we use if we are to confidently avoid future damage to the environment and human health. In Canada, procedures for acquiring this information have been set up under the 1988 *Canadian Environmental Protection Act* (CEPA). This gives the Minister of the Environment the authority to order testing and obtain toxicity information on any new chemicals entering the marketplace, as well as those already in use.

Under CEPA, a new chemical may not be introduced commercially into Canada until it has been approved by Environment Canada and Health and Welfare Canada. Anyone who develops a chemical or imports one for the first time must submit a set of physical, chemical, and toxicity data to the federal government for evaluation. Once it has assessed the risks posed by the chemical, the government can request more information, allow the chemical to be used without restriction, pass a regulation to restrict its use, or ban its use entirely.

FIGURE 21.5

Average mercury concentrations in walleye collected from Lake St. Clair, 1970–89



Source: Government of Canada (1991), based on data from the Ontario Ministry of the Environment.

Assessing chemicals already in use presents a more demanding problem because of the many thousands of substances involved. CEPA has established a Priority Substances List program to identify those chemicals that need to be dealt with most urgently. The first Priority Substances List was published in 1989 and contained 44 chemicals. Assessments of these are to be completed by 1994 (see Box 21.7).

Perception

Thorough scientific analysis is an indispensable base for the assessment of the risks arising from toxic chemicals. However, it would be a mistake to assume that it is the only factor influencing our responses to these materials. Subjective factors and the dynamics of social and political debate will also determine how we evaluate the risks of toxic chemicals and how we respond to them.

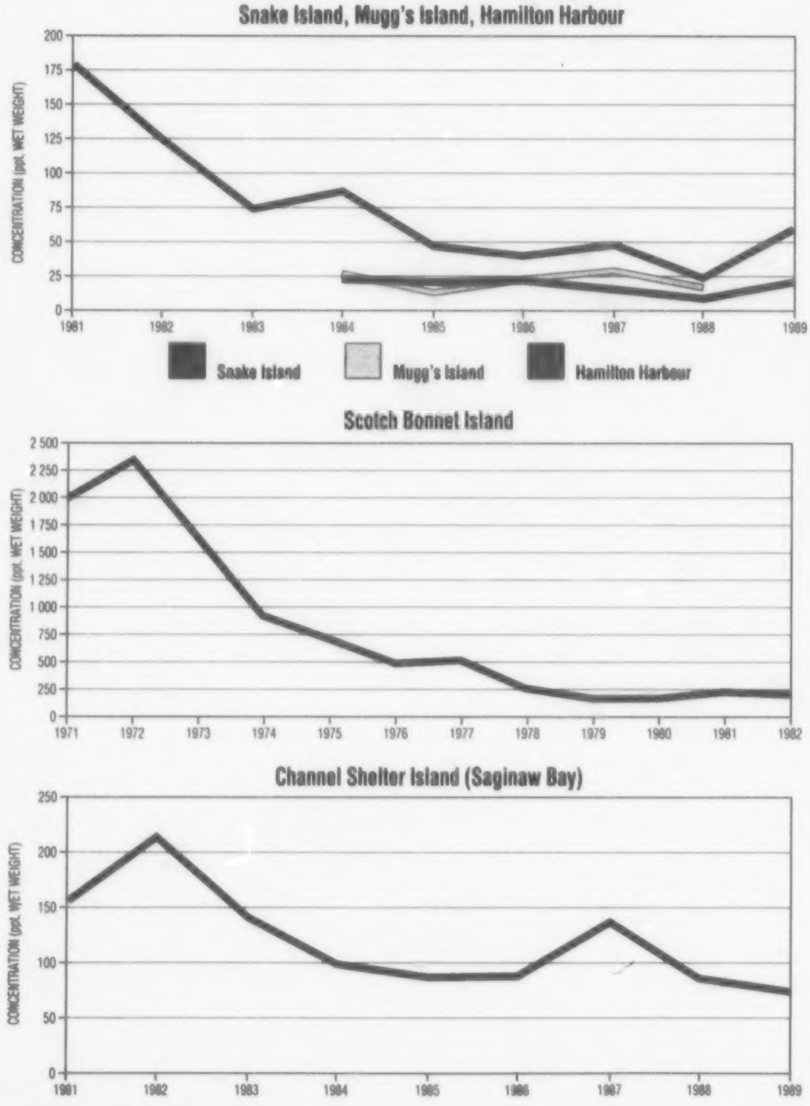
For example, two hazards may be equally deadly over a given period. One of them kills 100 people a year, but the deaths are spread randomly throughout the country. The other kills no one over a period of nine years but totally destroys a community of 1 000 people in the tenth. Statistically, one is no more hazardous than the other: the average death rate for both is 100 deaths a year. However, most of us are unlikely to rate these hazards equally. The sudden destruction of an entire community is simply more memorable, more frightening, and far more striking an event than the random, individual, and anonymous deaths of the same number of people. Consequently, we are inclined to perceive the catastrophic event as the greater risk (Sandman 1987).

The same kind of perceptual filtering may also affect our assessment of the risks posed by various toxic chemicals and influence our setting of priorities in dealing with them. Radon gas leaking into houses from naturally radioactive soils may well be a greater health risk than PCBs, but radon has not been associated with dramatic events like Minamata and is consequently the focus of far less public concern.

Our assessment of these risks will also be influenced by our values and interests. Currently, public debates about toxic chemicals are influenced largely by the values and interests of four different groups: industry, environmental groups, labour, and government. Although any one of these groups may

FIGURE 21.6

Dioxin (2,3,7,8-TCDD) concentrations in Herring Gull eggs


Snake Island, Mugg's Island, Hamilton Harbour

Scotch Bonnet Island

Channel Shelter Island (Saginaw Bay)

Note: Scotch Bonnet and Snake islands are at the eastern end of Lake Ontario; Mugg's Island is at Toronto.

Source: Government of Canada (1991), based on data from the Canadian Wildlife Service, Environment Canada.

itself contain a range of viewpoints, some generalizations can be made about the perspectives of each.

Industry, for example, defends economic interests, both its own and those of the economy as a whole. Consequently, it tends to balance the demands of the environment against those of the economy. Its major concern is that the economic costs of environmental control should be justified by a clear environmental benefit, a difficult proposition in those cases where scientific uncertainty makes benefits difficult to demonstrate. Industry is also concerned that environmental regulation may undermine the ability of Canadian firms to compete with those of other countries whose standards are less strict.

Environmental groups, on the other hand, place a high value on the need for society to be in harmony with the environment. They take the view that ensuring a healthy environment for future generations is both a moral and a practical imperative. Where the interests of industry and the environment are in conflict, environmental groups favour the environment regardless of the economic cost, arguing that, in the long term, the sustainability of the environment is a precondition for economic survival.

Labour unions, acting in defence of the interests of their members, have been found on both sides of chemical controversies. The right of people to earn a living without putting their health at risk is of great importance to labour. However, the preservation of jobs is also a key value. Thus, while unions may seek to restrict the use of some chemicals in order to protect the health of their members, they may also oppose restrictions on others on which their members' employment depends.

The role of government is the most complex, because it is government that must reconcile the other opinions as well as those of the public and decide on a course of action. Governments tend to favour economic and social stability. They have the benefit of the scientific advice and data-gathering capacity of the various government departments, but they, too, will be influenced by many other considerations, including personal perceptions.

Public opinion also has a major role to play in controversies over the management of chemicals, influencing the attention that government and industry pay to environmental issues. Governments, of course, are highly sensitive to public opinion, and environmental groups have been particularly astute in using this sensitivity as a lever to prompt them into action. Industry, too, has recognized the growing importance of gaining public confidence and has responded with environmental initiatives of its own to forestall regulation and repair its environmental image.

However, public opinion can also be an independent force and not just a factor to be influenced by particular interests. In particular, the so-called NIMBY (not-in-my-backyard) syndrome has added a further layer of complexity to the management of toxic chemicals. Communities, fearing a repetition of the Love Canal or Saint-Basile-le-Grand experiences, have become increasingly apprehensive about allowing any process connected with toxic chemicals, whether it is production, transportation, storage, or destruction, to occur within their boundaries (see Chapter 14).

APPROACHES TO TOXIC CHEMICAL MANAGEMENT

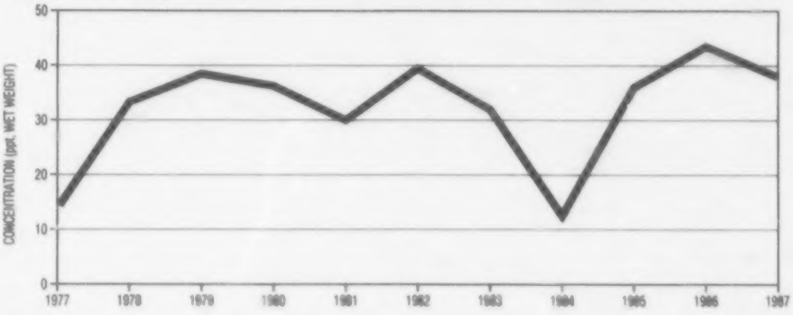
Four major approaches can be used for the management of toxic chemicals: voluntary guidelines, taxes and economic incentives, advocacy and information, and government legislation and regulation. Each has its particular advantages and disadvantages.

Voluntary measures can take the form either of guidelines developed by government in collaboration with industry, environmental groups, and others or of codes of practice that industries have developed for themselves. Guidelines are easier to prepare than regulations and can allow for more flexibility to meet specific situations. They work best in cases where the number of companies involved is small and their commitment to the guidelines is strong.

Company codes of environmental practice can be quite effective because they cover the whole of the company's operations and are prepared by people who have an intimate knowledge of the installations. They also make environmental values a part of the corporate culture and encourage employees to see the management of chemicals as an integral part of their jobs.

FIGURE 21.7

Average concentrations of the most toxic dioxin congener (2,3,7,8-TCDD) in whole lake trout from Lake Ontario, 1977–87



Source: Government of Canada (1991), based on data from the Department of Fisheries and Oceans.

The major disadvantage of voluntary activity is that it does not provide adequate mechanisms to ensure that good practices are really being followed. Moreover, some companies may be reluctant to participate in voluntary measures for fear of the costs or the effect on their competitive position. Voluntary action is often more effective in large companies, because smaller businesses often lack the awareness, financial resources, and technical expertise needed to undertake effective action.

Economic instruments are part incentive and part regulation. They are designed to reduce pollution by making it more expensive or, alternatively, by reducing the cost of pollution control measures through subsidies or tax write-offs.

One economic approach that has been much debated is emission trading, a concept that has been implemented in the United States and is being considered in Canada. Emission trading assumes that some polluters will be able to achieve or exceed requirements for emission reductions more easily than others. Instead of regulating each source of release, authorities set an industry target for total emissions and issue emission permits to individual companies. Companies that cannot keep within their emission limits may buy additional emission credits from companies whose emissions are less than the permitted amount. In this way, the desired emission reductions can be achieved with the least economic disruption to industry. Opponents of the scheme, however, argue that it allows some companies to continue polluting excessively while, in some cases, rewarding others for reductions they would have undertaken anyway.

TABLE 21.1

Median lethal dosage of 2,3,7,8-TCDD for various species

Animal	Dosage (mg/kg of body weight)
guinea pig	0.001
rat (male)	0.022
rat (female)	0.045
monkey	>0.07
mouse	0.114
rabbit	0.115
dog	>0.3
bullfrog	>0.5
hamster	5.0

Source: Chemical and Engineering News (1983).

The provision of information is a strategy that is usually aimed at individuals. The Workplace Hazardous Materials Information System (WHMIS) is a recent example of this kind. A joint initiative of government, industry, and labour, it is intended to make the growing database of information about

BOX 21.7

The Priority Substances List

Because toxicity testing and other environmental assessments were not carried out routinely in the past, some chemicals now in use may present environmental and health risks that no one is aware of. Often attention was drawn to chemical hazards only after serious environmental or health damage had already been done. To diminish the likelihood that this kind of problem will happen again, the *Canadian Environmental Protection Act* (CEPA) of 1988 has stipulated that a thorough review of all chemicals currently in use in Canada must be undertaken.

With approximately 35 000 chemicals in commercial use in Canada, this is an enormous task that will take many years to complete. To ensure that the most harmful chemicals are identified as early as possible, CEPA has established a Priority Substances List. A substance is selected for the list if it meets at least one of the following criteria:

- it causes or has potential to cause adverse effects on human health or the environment;
- it accumulates or could accumulate to significant concentrations in air, water, soil, sediment, or tissue;
- it is released into the environment in significant quantities or concentrations.

As well, citizens may request that a chemical be included on the list by writing to the Minister of the Environment and stating the reasons for adding it. Substances already regulated by CEPA or other legislation are excluded from the list.

Once a chemical is placed on the list, it undergoes testing to determine the extent and nature of the risk it presents. Options for controlling the chemical are identified, and, if necessary, regulations are introduced and enforced. The process concludes with a review of the effectiveness of the actions taken.

The first Priority Substances List was published in February 1989. Of the 44 substances listed, approximately one-third are families of chemicals, which may comprise as many as several hundred individual substances. Assessments of these must be completed by February 11, 1994.

The substances scheduled for earliest assessment are:

- arsenic and its compounds;
- benzene;
- effluents from pulp mills using bleaching;
- hexachlorobenzene;
- methyl tertiary-butyl ether;
- polychlorinated dibenzodioxins;
- polychlorinated dibenzofurans;
- polycyclic aromatic hydrocarbons;
- waste crankcase oils.

The first report, on dioxins and furans, was released in March 1990.

hazardous chemicals available to workers so that they can take appropriate action to protect their health. Another effort, this time aimed at consumers, is the Environmental Choice Program, which awards a label to "environmentally friendly" products. However, although information programs have a valuable role to play, especially in the long run, they are effective only to the degree that people act on the information provided.

Government regulations have the advantage of setting visible, legally enforceable standards. Because all companies are bound by the same rules, they remove any competitive advantage that could be gained by using less than stringent environmental controls. They are also the only effective way to control the use of individual chemicals and to ensure consistency in labelling and other practices. In theory, regulations can ensure certainty and uniformity in the achievement of environmental standards.

However, regulatory processes are time-consuming and tend to be applied only to chemicals for which an extensive database is available. As a result, only a very small number of chemicals have been regulated. For a variety of legal, technical, and financial reasons, enforcement has also proved to be a major challenge. In addition, many of the actions that can help to limit releases, such as good operating practices, worker training, and the development of clean technologies, are difficult to mandate in regulations.

Nevertheless, regulations have become increasingly important in the management of toxic substances. Although the control of emissions and effluents is largely a provincial responsibility, the regulation of chemicals in commerce comes under the authority of the federal government. CEPA is the main instrument for regulating individual chemicals.

If a chemical is toxic, regulations may set an allowable level of release, based on the health and environmental effects, the economic and social impacts of controls, the availability of alternatives, and the performance of the control technology.

In some instances — especially in the case of carcinogenic or highly persistent chemicals — releases may be banned altogether. Opinions differ as to how wide a range of chemicals should be affected by such zero-discharge policies. Some see little value in imposing extra controls on a chemical if releases are already low enough to pose little risk. The extra measures, they suggest, could involve substantial expense for relatively little return. Others, however, take the position that there is no margin for error in dealing with toxic or potentially toxic substances that could remain in the environment for centuries.

The more cautious approach seems to have made headway. The Canada–U.S. Great Lakes Water Quality Agreement, for example, requires that "the discharge of toxic substances in toxic amounts be prohibited and the discharge of any or all persistent toxic substances be virtually eliminated" (International Joint Commission 1978). Similarly, the ultimate goal of Ontario's Municipal/Industrial Strategy for Abatement is "the virtual elimination of toxic contaminants in municipal and industrial discharges into waterways" (Ontario Ministry of the Environment 1986).

Recent regulations under CEPA have also set a "virtual elimination" target for dioxins and furans in the effluent from pulp and paper mills. This target will involve modifications to the chlorine bleaching process and is to be reached by 1996.

FROM CRADLE TO GRAVE: A FRAMEWORK FOR MANAGING TOXIC CHEMICALS

To find a more systematic and comprehensive way of dealing with chemical issues, the federal government began consultations in 1985 with representatives from the provincial governments, industry, labour, environmental groups, and consumers. A task force was struck and given the objective of developing a management framework for toxic chemicals that would minimize the risks to human health and the environment while maintaining industrial productivity. The result of their deliberations was the concept of cradle-to-grave management, an approach to controlling chemicals at each of the seven stages of their life cycle: research and development, introduction to the market, manufacturing, transportation, distribution, use, and disposal (Environment Canada 1986*a*).

Since then, the concept of cradle-to-grave management has significantly shaped both legislative and voluntary initiatives for controlling toxic chemicals. It underlies many of the provisions of CEPA and forms a basis for the Codes of Practice embodied in the Responsible Care Program of the Canadian Chemical Producers' Association (see Box 21.8).

Among the more significant features of the cradle-to-grave approach is an emphasis on prevention and on the need to establish limits to human and environmental exposure, even in the face of scientific uncertainty. New and existing chemicals have been treated equally in the setting of action priorities. An attempt has also been made to streamline the formulation of responses by establishing greater cooperation among the various parties involved in toxic chemical issues and by harmonizing federal and provincial laws and policies. The following outline summarizes the principal issues that arise at each stage of the life cycle.

Research and development

The main concerns of chemical management at this stage focus on the health and safety of research personnel, the consideration of potential risks that may arise during the life cycle of the chemical, and the proper disposal of samples and effluents. Because the work at this stage is carried out by specialized chemists in well-equipped laboratories, the environmental risks are small, although the potential for releases to the environment increases in the later research stages when larger amounts of experimental chemicals are produced in a factory.

Introduction to the market

After a chemical has been developed, its market potential is evaluated and it is prepared for commercial production. A central concern at this stage is the assessment of the potential health and environmental hazards that the chemical may present at any point in its life cycle, and the preparation of information on its toxicity, stability, and other physical and chemical characteristics. This information must be submitted to the federal government before permission can be obtained to release the chemical for commercial use. Such information will also be needed by the manufacturer's employees and customers.

Manufacturing

At the manufacturing stage, chemical management focuses on siting and construction standards for the facilities, the integrity of the plant, operating and maintenance procedures, worker health and safety, effluent disposal, and contingency planning in case of emergencies.

During manufacturing, air emissions, liquid effluent, and solid wastes are generated that may carry unwanted chemicals into the environment. The release of these by-products, either directly to the environment or to sewer systems, is controlled largely by provincial regulations.

In many plants, however, a significant volume of chemicals can escape from leaks in equipment. In older facilities, these so-called fugitive emissions can account for up to 40% of the releases from the plant (A. Stelzig, Environment Canada, personal communication). Although most large companies have some form of maintenance program to prevent such leaks, their thoroughness varies (D. Bisset, Shell Canada, personal communication). With some

BOX 21.8

Self-regulation in the chemical industry

The chemical industry has responded to growing public concern about hazardous materials with a variety of voluntary measures to improve the management of chemicals. The Responsible Care Program of the Canadian Chemical Producers' Association embodies six codes of practice that cover the entire life cycle of chemical products, from research and development through manufacturing and transportation to distribution and disposal (Canadian Chemical Producers' Association 1990*b*). The codes were developed by experts from member companies and were designed to ensure consistency in the management of chemicals throughout the industry.

The *Community Awareness and Emergency Response Code* requires companies to have programs in place to inform community members, workers, and other interested parties about the hazards and risks associated with the company's operations and products, to discuss and respond to community concerns, and to deal with emergencies and assist community authorities with emergency response planning.

The *Research and Development Code* is intended to ensure that the public and the environment are not exposed to hazards as a result of the development of new products, processes, equipment, or applications. It also requires that full information about a product's risks and its handling and disposal requirements be made available when it is introduced to the market.

The *Manufacturing Code* is designed to protect the public and the environment from hazards associated with manufacturing from the time a plant is designed and built to the time it is decommissioned. In addition to having emergency response and hazard information programs in place, companies have to ensure that employees monitor all effluents and emissions to the environment and develop any measures needed to control these.

The *Transportation Code* sets standards for equipment, procedures, and personnel involved in the transportation of chemicals. It also requires carriers to choose routes that will minimize the exposure of people and environmentally sensitive areas to potential chemical hazards and to have emergency response plans that they can implement in the event of an accident. Through the Transportation Emergency Assistance Program, several regional centres have been set up to provide skilled personnel who can respond quickly to chemical transportation emergencies.

The *Distribution Code* provides for the regular evaluation of the risks associated with the storage and handling of chemicals during distribution. Member companies are not permitted to supply distributors and customers who cannot comply with the code.

The *Hazardous Waste Management Code* deals with all aspects of the handling and disposal of hazardous wastes, as well as the closure and care of disposal sites. Companies are encouraged to reduce, reuse, and recycle waste materials where technically and economically feasible. If a company cannot conform to the code's requirements for safe disposal of a substance, it must cease those operations that produce it.

The program provides assistance with implementation of the codes and outlines criteria for monitoring results. Adherence to the Responsible Care Program and its codes of practice is a condition of membership in the association.

exceptions, the only regulatory controls on fugitive emissions in Canada are those within occupational health and safety regulations designed to protect workers from exposure to chemicals. For both environmental and economic reasons, improvements are being made to plant and equipment design in order to reduce the release of chemicals. In general, the newer a manufacturing facility is, the lower its emissions to the environment are likely to be.

The release of chemicals as a result of industrial accidents is also a concern. Although municipalities that have a high concentration of chemical industries — such as Sarnia, Ontario — tend to have well-developed emergency response systems, other communities are not so well prepared. A major review of the Canadian situation, carried out in the wake of the Bhopal disaster of 1984, identified 21 areas where improvements were needed. These ranged from preventive measures for industries and municipalities to better planning for emergency response (Environment Canada 1986*b*). Industry–government task forces are now working to implement the report's recommendations under the aegis of the Major Industrial Accidents Committee, chaired by the federal government.

The decommissioning of manufacturing plants at the end of their useful life is also an important issue, because the site must be made clean enough to be returned to other uses. Some of the questions that typically arise in such situations include the following: What is the extent of the cleanup required? What is the safe level of contaminants that can be left in the soil? Should some uses not be allowed on the site? Approval from the provincial government is usually required to decommission a site, but the guidelines currently differ from one province to another. A set of national guidelines for the decommissioning process is currently being considered by the Canadian Council of Ministers of the Environment.

Transportation

The main preoccupation of chemical management at the transportation stage is public safety. The movement of hazardous chemicals is regulated by the *Transportation of Dangerous Goods Act*, which requires special training for vehicle operators, safe packaging and handling of dangerous materials, and the use of placards to identify hazardous materials. Those transporting very dangerous substances (such as explosives, large quantities of chlorine, or radioactive or infectious materials) are required to submit an emergency response plan before moving the material. In addition, both government and industry are required to have emergency response plans in place to deal with other transportation mishaps.

Large urban areas are often the destination for many shipments of hazardous chemicals. To minimize the hazards involved in moving these through city streets, municipalities such as Montreal, Toronto, and Vancouver have set up task forces to determine the safest routes for these vehicles.

Distribution

Chemicals are distributed to users in many different ways, sometimes directly from the manufacturer, sometimes through one or more small or medium-size firms that sell the chemicals to users or act as packagers, processors, formulators, or import/export agents. The important concern at this stage is that all pertinent information for the safe management of the chemical accompanies the product to the end user, regardless of the distribution channel used.

The export of chemicals is an area of special concern. Regulations to be implemented under CEPA will require the exporter of a substance that is banned or severely restricted in Canada to notify the government of the importing country of the shipment in advance of its arrival. Information on the chemical's properties must be included in the notification package.

The use of chemicals

Chemical users consist of industries, institutions, and consumers. Although industrial and institutional users must deal with many of the same concerns as manufacturers, the capacity of individual companies to handle these varies considerably.

Most chemical companies work closely with their customers to ensure responsible use of their products. Dow Chemical Canada, for example, inspects its customers' plants when a product is first delivered and on a regular basis (every six months to three years) thereafter. Dow will provide technical assistance and advice to any customer that does not meet its standards for safe operation. Should a customer be unwilling to upgrade its operation, however, it is Dow's policy to stop supplying it with chemicals (D. Hames, Dow Chemical Canada, personal communication).

Small and medium-size users are often unaware of the solutions to the problems they may be causing. Indeed, many may not even be aware of the problems. Corner dry-cleaning shops, for example, use perchloroethylene and other hazardous chemicals, but the operators and employees often lack the training and facilities to manage these chemicals safely. Manufacturers of dry-cleaning solvents now have programs under way to improve the practices of these users, but there remains a need for more programs to assist small companies in other sectors to improve their environmental practices.

Domestic consumers must also be involved in the management of chemicals. The average home contains a profusion of products that release potentially harmful chemicals to the environment. Cleaning agents and pesticides are obvious examples, but even seemingly innocuous products such as oil-based paints, perfumes, and nail polish removers contain solvents that release toxic chemicals when they evaporate.

To manage household chemicals safely, consumers need information on the proper use and disposal of these products as well as advice on choosing products that have the least environmental impact. In this respect, the provision of adequate information on product labels and accompanying brochures is particularly important. Consumers can also get more detailed information about specific chemicals from local poison control centres or through various toll-free telephone services. The Chemical Referral Centre of the Canadian Chemical Producers' Association provides one such service, and Agriculture Canada provides another for pesticides. As yet, however, there is no consumer equivalent to WHMIS to provide consumers with detailed information on hazardous chemicals. Such a system would be a boon to people who are very sensitive to certain chemicals and need to know the specific ingredients of the products they buy in order to avoid substances they are sensitive to.

For many years now, environmental groups have played a major role in informing consumers of toxic materials and in encouraging more environmentally benign lifestyles. More recently, the federal government's Environmental Choice Program has attempted to inform consumers and to encourage manufacturers to produce environmentally friendlier products by awarding a logo to items that have a reduced environmental impact.

The disposal of chemicals

Once a chemical has been used, its residues may still be a serious threat to the environment and to human health. Inadequate disposal of hazardous wastes in the past has been the source of some of today's most serious environmental problems, and implementing a safe and efficient way of handling these wastes remains one of the major challenges to effective chemical management.

It is estimated that 6.08 million tonnes of hazardous waste were generated in Canada in 1986. Approximately 60% of these wastes were treated on site by the producer, and the remaining 40% were treated off site. Based on projections of economic growth, the total quantity of hazardous waste is projected to increase to 6.5 million tonnes in 1992. Table 21.2 shows the relative contribution of each province to the total quantity of hazardous waste produced in Canada in 1986.

How well are these wastes managed? The simple answer is that no one really knows. A recent study by a commission of inquiry in Quebec, for example,

TABLE 21.2

Proportion of national total of hazardous waste generated by each province

Province	% of total
British Columbia	1.4
Alberta	1.6
Saskatchewan	0.9
Manitoba	0.8
Ontario	68.1
Quebec	22.2
New Brunswick	1.1
Nova Scotia	2.6
P.E.I.	0.01
Newfoundland	0.4

Source: Fenco Newfoundland Lavalin (1988).

was often unable to find adequate information about key questions such as whether wastes were reused or treated or whether the treatment was adequate and within legal norms. Moreover, approximately 108 000 t, or nearly one-third, of the waste treated off site could not be accounted for. Exactly where and how these wastes were disposed of, no one knows.

The problem of household hazardous wastes also needs to be addressed more thoroughly. It has been estimated that each Canadian produces about 2.5 kg of hazardous waste a year, consisting of such items as paint, solvents, batteries, pool chemicals, pesticides, and cleaners. Nationwide, this adds up to nearly 64 000 t a year (Commission d'enquête sur les déchets dangereux 1990).

Some municipalities now hold annual household hazardous waste days, when the public can bring in wastes for proper disposal. The Canadian Petroleum Products Institute (1990) has also set up a recycling system for used lubricating oil. However, in spite of these initiatives, the major barrier to the safe disposal of household hazardous waste remains the lack of an adequate collection system.

The three Rs: reducing, reusing, recycling

The best waste disposal strategy is not to produce waste in the first place. In many situations, waste output can be reduced by changing manufacturing processes. In some cases, the quantity of hazardous residues or their toxicity can be reduced by using different chemicals.

Waste is considered reused if it is used without modification or further processing. To facilitate the transfer of reusable wastes among companies, the Canadian Waste Exchange acts as a broker to match producers of wastes with companies that can use these materials in their operations. Wastes that must be processed before being reused are said to be recycled.

To be effective, the three Rs must be applied systematically to all aspects of a company's operations, from the design of plants and equipment to the creation of products. Although the three Rs may save money by reducing raw material and waste management costs (Munro *et al.* 1990), their adoption by industry has been slow. Some companies do not know the composition of their wastes or how the three Rs could be applied to their operations. Others cannot afford the capital cost of the new equipment that might be needed. Still others do not perceive waste as the resource that it is. In some cases, too, the option is not open for purely chemical or physical reasons.

Incineration and landfill

Once a company's wastes have been reduced, recycled, and reused, incineration and storage in a secure landfill are the principal disposal options for those that remain. However, both of these options are the subject of considerable controversy.

Incineration involves the burning of toxic wastes at very high temperatures in specially equipped incinerators or cement kilns. PCBs are now being destroyed using equipment that is designed to ensure the destruction of at least 99.9999% of the waste material without producing toxic by-products such as dioxins and furans. Proponents of incineration contend that it is safe and could also offer additional benefits as a method of energy generation. However, opponents of the procedure believe that the possibilities of transportation or on-site storage mishaps and equipment malfunctions still pose an unacceptable risk to nearby communities and argue that more emphasis should be put on the three Rs to solve the toxic waste problem. For many communities, the use of mobile incinerators represents an acceptable compromise. These minimize the need to transport hazardous wastes to the destruction site and have the added attraction of leaving the community when the job is done.

A similar controversy exists over the landfilling of the incinerator ash and other wastes that cannot be burned. Although processes to neutralize or seal the waste exist, their effectiveness over the long term has been questioned. Furthermore, the reluctance of communities to accept disposal sites in their area has all but brought this activity to a halt.

While the arguments go on, the volume of hazardous waste continues to grow. Present incineration facilities have not kept up with the output of toxic wastes, and the three Rs have not yet significantly reduced it. However, the growing acceptance of mobile incinerators may finally break the stalemate, making it possible to diminish existing stockpiles of these dangerous materials while Canadian industry improves its capacity to reduce, reuse, and recycle them in the future.

Cleaning up contaminated sites

Across Canada, an estimated 1 000 sites are contaminated with hazardous materials. These include coal tar pits, leaking landfills, old plant sites, and storage facilities, many of which must be cleaned up at public expense because the owners have long since disappeared. Depending on the nature of the contamination, the size of the site, the cleanup method used, and several other factors, the costs can vary from several hundred thousand dollars to tens of millions of dollars (Energy Pathways Inc. 1990).

At present, some of the more visible sites are being cleaned up. The Canadian Council of Ministers of the Environment has initiated a program to set guidelines for these activities and to fund the cleanup of sites where the parties legally responsible for the problem cannot be identified (see Chapter 14).

TAKING RESPONSIBILITY: CHEMICAL MANAGEMENT AND CULTURAL CHANGE

As with so many other environmental issues, Canada's toxic chemical record in the early 1990s is mixed. Over the past two decades, Canadians have moved from heightened awareness of the issues to action against some of the more serious chemical threats to the environment and, in particular, to people. Yet serious problems of chemical contamination remain. Why is this so?

Part of the answer is that for many years chemicals were used without proper safeguards. Part of the challenge facing Canadians is to learn from the past and to find the ways, the will, and the funds to avoid those errors in the future.

Another aspect is the difficulty of changing the physical infrastructure of society. To reduce the release of chemicals, many buildings and machines need to be upgraded or replaced and cleaner technologies and safer chemicals need to be developed and implemented.

Similarly, Canadians have to adapt socially and institutionally to meet the needs of managing chemicals. More arrangements to facilitate the collection, recycling, and safe disposal of wastes need to be set up, along with systems to gather and analyze information on how chemicals are used and where they end up. Additional standards, regulations, guidelines, and codes of practice are also needed.

Finally, individual attitudes and habits have a significant role to play. Despite our increased awareness of the toxic chemical threat, consumers are only beginning to take environmental factors into account in their purchasing decisions. Also, there are still many instances in which chemicals are treated carelessly in both the home and the workplace. The careful management of chemicals must become second nature both to individuals and to institutions.

Is it practical to assume that Canadians can make not only the financial commitment but also the economic, social, and individual changes needed to ensure the safe management of chemicals? A historical precedent suggests that it is.

Before the 19th century, little attention was paid to sanitation and hygiene. Household wastes were tossed into the street, drinking water was not purified, and sewage ran in open sewers. Not surprisingly, diseases such as cholera, typhoid, and dysentery took a large toll of lives. During the 19th century, however, several things happened to bring about a revolution in thinking about hygiene. The germ theory of disease, which pointed to unsanitary conditions as a major cause of illness, became generally accepted. Government commissions recommended improved sanitation measures, and public interest groups, such as the Canadian Public Health Association, were formed to pressure governments and educate the public about sanitation. Major outbreaks of disease reinforced their arguments and focused public attention on the need for improved public hygiene. By the closing decades of the 19th century, action was getting under way in many parts of Canada to provide sewage disposal, water purification, refuse collection, and other essential aspects of public sanitation.

The most important change, however, was in the collective consciousness of the population. Unhygienic conditions that were once common in homes and communities are now not only unacceptable but unimaginable. Although regulations remain necessary to ensure sanitary conditions in restaurants and other public services, their application is a routine and accepted part of modern life. The ease with which hygiene is now regulated reflects the fact that it has become a part of the broader culture and of how people think about the world and educate their children.

What has been accomplished in the management of hygiene can also be accomplished in the management of chemicals. An expanded infrastructure of laws and institutions is a necessary part of making this happen, of course, but a fundamental change in attitude towards chemicals is equally important. Just as sanitation and hygiene have become an integral part of public and private culture, so, too, must the management of chemicals.

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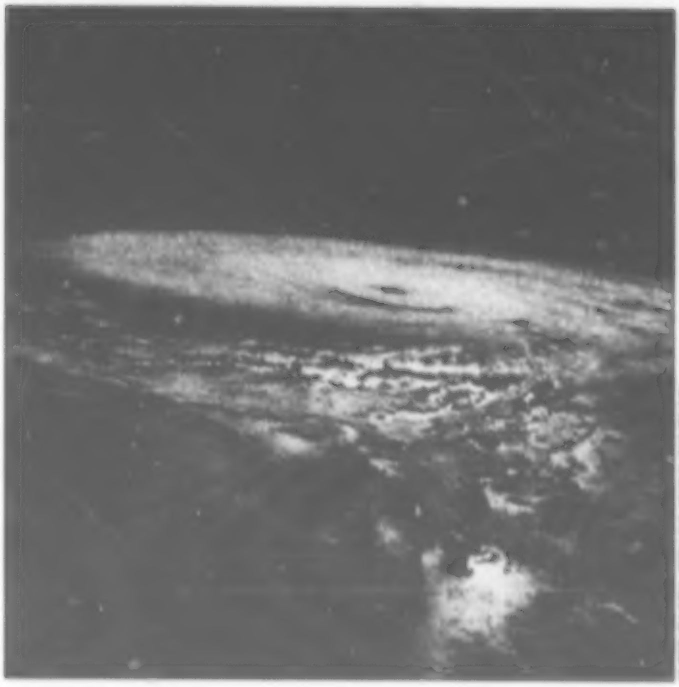

HIGHLIGHTS

Canadians are responsible for about 2% of the current global increase in atmospheric levels of natural greenhouse gases, such as carbon dioxide, and synthetic greenhouse gases, such as chlorofluorocarbons.

■

Analysis of glacial ice cores has revealed strong positive correlations between air temperature and atmospheric concentrations of carbon dioxide and methane over the past 160 000 years. With an increase in greenhouse gases equivalent to a doubling of carbon dioxide over pre-industrial levels, winter temperatures could rise as much as 11°C in parts of northern Canada. Summer temperatures could increase 4–5°C over much of the nation.

■

The Canadian economy is highly dependent on climatically sensitive activities, such as agriculture, forestry, and fishing. In the case of agriculture, climatic warming would lengthen the growing season, but some regions such as the prairies might experience a higher incidence of severe drought. In addition, generally poor soils would hinder any significant northward advance of agriculture, in spite of more favourable climatic conditions.

■

Benefits should accrue in some cases. Space heating costs would decline, and navigation seasons on the Great Lakes and in the Arctic would lengthen. However, should water levels on the Great Lakes fall, vessels of lesser draft would be needed, or shallow channels would have to be dredged.

■

Mean global sea level is already rising and, with global warming, will rise even faster, as glacial ice melts and the seas expand as they warm. This has major implications for the coastal zone — for example, a loss of coastal wetland habitat, inundation of coastal facilities, and saltwater intrusion into groundwater reservoirs.

■

This is a global problem, demanding global-scale responses. Canada can lead by example, adopting measures that control greenhouse gas levels or anticipate likely changes arising from warming.

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> “Everybody talks about the weather, but nobody does anything about it.”
>
> — Charles Dudley Warner (1897)

INTRODUCTION

Some 10 000 years ago Earth emerged abruptly from the latest of its periodic ice ages, and the present milder period began. Over a period of a few thousand years the planet warmed rapidly, the vast ice sheets retreated, and the physical world was radically transformed. Because living things have an intimate dependence on climate, the end of the last ice age brought a massive redistribution of ecosystems, as species colonized newly hospitable environments, abandoned old environments that had become hostile, or perished because they could not adapt to changing conditions.

Since the last glaciation, climatic conditions have been comparatively stable, with the Earth's average surface temperature varying only within a degree or two of today's values. Yet even these relatively modest fluctuations have often had striking effects on natural environments and the distribution and survival of species.

Human populations have flourished to an unprecedented degree during this period, establishing permanent agricultural societies and developing elaborate and sophisticated civilizations. But human societies, too, are dependent on climate for survival, and the climatic fluctuations of the past 10 000 years have influenced the abandonment of settlements, the migration of populations, and even the collapse of civilizations.

Human civilizations have not yet experienced a climatic change as large as the one that occurred at the end of the last ice age. However, over the next several decades, we may witness climatic changes that transcend any yet experienced in the age of human civilization and that have no parallel in the recent geological record. As early as the middle of the next century, average surface temperatures on Earth could be warmer than at any time during the past several million years. But this transition will be unlike previous climatic changes in two significant ways. First, it will occur much more rapidly than past changes of similar magnitude, and secondly, it will not be the product of natural forces. Instead, it will be the outcome of a human disruption of a balanced natural system: the result of gases that people have released into the atmosphere and changes to the land that, together, have decisively altered the composition of the atmosphere.

Estimates of the possible extent of future warming vary. However, a recent study by an international panel of scientists suggested that the globe may warm by an average of 1°C in the next 35 years and 3°C by the year 2100, unless strong measures are taken to reverse current trends in emissions of these gases (Intergovernmental Panel on Climate Change 1990). Such temperature changes might seem relatively insignificant, but it should be borne in mind that they are global averages and that the difference between average global surface temperatures now and at the peak of the last ice age is a mere 4–5°C. Moreover, today's warming could occur up to 100 times faster than the warming at the end of the last ice age.

Such rapid and profound climatic changes can be expected to have far-reaching and, in many instances, unpredictable consequences not only for human societies but for all forms of life on Earth. The direct effects of such a warming would include changes in the frequency, amount, and seasonal distribution of precipitation, a tendency for increased evaporation and drying of continental interiors, a rise of sea level, changes in oceanic currents, a thawing of permafrost, and the melting of snow and sea ice. Canada, with the longest shoreline of any country in the world, its vast interior lakes, and permafrost under half its land area, cannot avoid being affected.

In addition, Canada is highly dependent on climatically sensitive activities such as agriculture, forestry, and fishing. Climatic change will impose heavy stresses on the biological bases of these industries. In many cases, it will also exacerbate the effects of other atmospheric stresses, such as increased exposure to ultraviolet radiation, photochemical smog, and acidic deposition.

These simultaneous pressures are likely to cause significant dieback and impoverishment of forests worldwide and to provoke further extinctions of plant and animal species, in addition to those already caused by the human destruction of natural habitats.

World agricultural systems will be hard pressed to meet the needs of a growing human population. Some regions are likely to see agricultural yields reduced; although others may see increases, it cannot be predicted in advance who will gain and who will lose. Even "winners" are likely to be adversely affected by reduced food production elsewhere and the resultant economic and political instability. And with rapid, open-ended climatic change, winners at one time may become losers at another. Everyone will be at risk.

The prospect of a large and rapid climatic change has come about mainly because of energy-related activities (which are also the primary cause of the concurrent problems of acidic deposition and air pollution). To avert the worst effects of a rapid global warming, Canadians and citizens of other industrialized countries must contemplate a fundamental shift in the kinds and amounts of energy they use, and they will have to make adjustments in their lifestyles. If citizens of these countries move quickly and aggressively, they will avoid many of the impacts of rapid climatic change, but they are unlikely to avoid them all.

CLIMATE AND THE CLIMATE SYSTEM

What is climate?

Intuitively, most people understand climate to be the customary long-term weather pattern of a region. They think of it in terms of such things as typical seasonal temperatures, the amount of snowfall in winter, the tendency for summers to be wet or dry, the relative frequency of extreme events such as tornadoes or blizzards, and so on.

Scientifically, climate can be quantified in two ways: first, in terms of the *average* values of key climatic elements such as temperature, precipitation, hours of bright sunshine, length of growing season, ice amounts, and so on, and, secondly, in terms of their *variability*, the extent and frequency of their departures from the average values. For example, one need only compare temperature values for Toronto and Prince Rupert. Average annual temperatures for both are similar: 7.3°C for Toronto's international airport and 6.7°C for Prince Rupert's air[illegible] variability of temperature is no[illegible], however, because the difference between average temperatures for January and July is a substantial 27.3°C for Toronto but only 13.3°C for Prince Rupert. The result, in terms of temperature alone, is two very different climates: one marked by cold winters and hot summers, the other by mild winters and cool summers.

When climate changes, therefore, the shift will show up as a change in averages, or variabilities, or both. Small changes in averages, even without a change in variability, can cause large changes in the frequencies of extreme events. Thus, a small rise of, say, 1°C in average temperature could cause a significant increase in the number of heat waves in certain localities. It is through such changes in the frequencies of extreme events that climatic change is most likely to be felt. For most people, this will mean an increase in weather hazards. For those whose activities are directly affected by climatic variability, it will mean new difficulties and challenges. Farmers, for example, may face an increased threat of drought, whereas engineers may have to accommodate the possibility of new weather extremes in the design of their structures.

The climate system

The Earth's climate system is made up of a complex array of interacting elements. The prime mover of the system is the sun, whose energy heats the Earth and thus moves the air and the oceans and drives the evaporation and precipitation processes of the water cycle. But many other factors affect how this energy is absorbed and shared around the globe and, thus, how Earth's climate is shaped. In addition to the atmosphere and the oceans, the climate system includes fresh water, plants and animals, ice and snow, land masses, and even the Earth's crust.

One of the most crucial roles within this system is played by certain gases within the atmosphere that absorb infrared radiation. These are the so-called greenhouse gases. The most abundant is water vapour, but other naturally occurring gases — carbon dioxide (CO_2), ozone (O_3), methane (CH_4), and nitrous oxide (N_2O) — are also present in trace amounts. The Earth reemits the energy it has absorbed from the sun as infrared radiation, part of which the greenhouse gases absorb and reemit within the lower atmosphere, with the net effect of raising the temperature at the Earth's surface by about 33°C. Because of this "greenhouse effect," as it is commonly called,[1] average temperatures on Earth remain within the range necessary for the existence of life as we know it.

Because the various elements of the climate system operate as an interconnected and balanced whole, any change in one element is likely to cause changes in the others, forcing the system to readjust until a new balance is achieved. Change is, in fact, a basic characteristic of the system and occurs on many different scales of time and magnitude, from minor fluctuations over decades or centuries, to ice-age oscillations on a 100 000-year time scale, to 100-million-year alterations governed by tectonic processes.

Evidence of past changes in Earth's climate is abundant. Testimony to the ice ages can be found in the landforms produced by the advance and retreat of the great ice sheets. Further evidence can be found in the chemical characteristics of marine sediments and polar ice masses and in the changing ratios of pollen found in lake and bog sediments.

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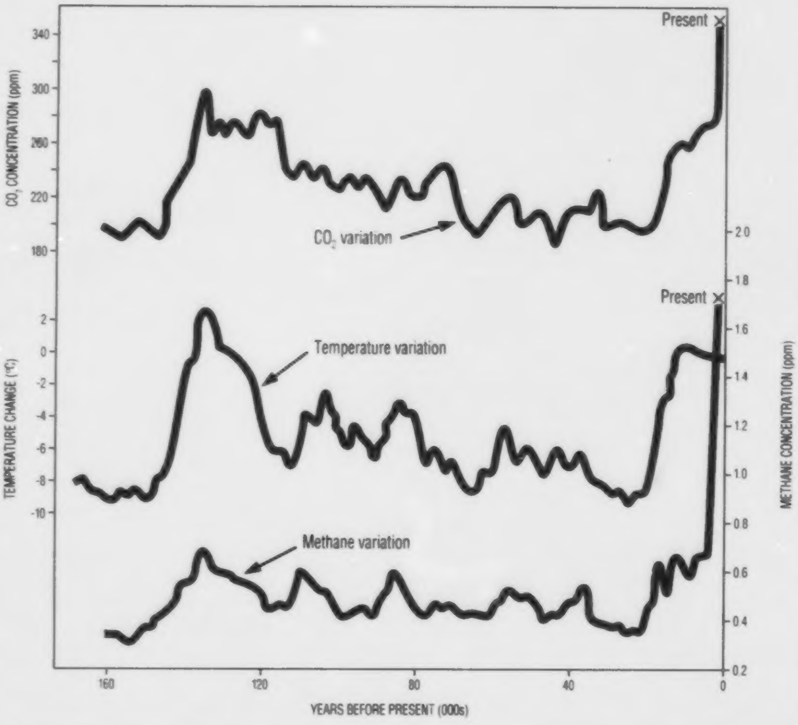
[1] The term "greenhouse effect" is, in fact, a misnomer, because a greenhouse traps relatively little infrared radiation. It is warm primarily because it prevents convective heat exchange with the surrounding air.

FIGURE 22.1

Variation of temperature over Antarctica and of global atmospheric carbon dioxide and methane concentrations during the last 160 000 years, as inferred from the Vostok ice core from Antarctica



Source: Chappellaz *et al.* (1990).

The 100 000-year cycle of glacier growth and decay can be traced through these records for the past 600 000 years.

Our present climate came into being about 10 000 years ago, with the end of the last ice age. Since that time several smaller-scale climatic changes have occurred. Plant fossils and soil development, for example, indicate that the northern tree line repeatedly shifted by several hundred kilometres north and south (Sorenson *et al.* 1971). Similarly, glacial moraines and lake sediments in the Canadian Rockies indicate that alpine glaciers underwent several expansions and retractions, while parallel shifts occurred in montane vegetation zones (Luckman and Kearny 1986).

Climatic change may be triggered by changes within one or more of the internal elements of the climatic system or by factors external to it. The oscillation between glacial and nonglacial conditions that has characterized the last two and a half million years of the Earth's history, for example, was triggered externally by periodic variations in the Earth's orbit, occurring on time scales of 10 000–100 000 years. Variations in the energy output from the sun or in the frequency and intensity of volcanic eruptions might also have been responsible for some climatic changes. On a multimillion-year time scale, shifts in the positions of continents, the uplift of mountain ranges and plateaus, and the opening and closing of seas (such as the Mediterranean) have played an important role in past climatic changes.

The extent of these changes is often determined by the existence of internal feedback mechanisms among the components of the climate system itself. Negative feedbacks will moderate a change by creating changes in other elements of the climate system that offset the initial change. A warming of the climate, for instance, might cause low-level cloud cover to increase as a result of higher levels of evaporation. The additional cloud would then diminish the amount of solar energy reaching the surface and have a cooling effect, thus offsetting the original warming.

Many of the interactions between components of the climate system are negative feedbacks, and they serve to stabilize the system. Positive feedbacks, on the other hand, amplify the original change. If a warming of the climate causes large areas of ice and snow to melt, for example, the Earth's surface will become less reflective and absorb more solar energy, thus adding to the warming effect.

The various positive and negative feedbacks come into play on vastly different time scales. As a result, climate is variable and contains an endless set of weather patterns. Often, the responses remain small until some threshold is reached, and then a large and sudden change occurs. The geological record suggests that the climate system can rapidly shift from one long-term mean state to another, with each state containing its own special patterns of variability.

One of the most striking features of past climatic variations is the remarkably close correlation between temperature and atmospheric concentrations of carbon dioxide and methane, two of the most important greenhouse gases. This can be seen clearly in Figure 22.1, which compares Antarctic temperature variations over the past 160 000 years with atmospheric concentrations of carbon dioxide and methane for the same period. The data are derived from ice cores drilled deep into the antarctic ice cap. Temperatures have been inferred from the chemical composition of the ice, and carbon dioxide and methane concentrations have been taken from air bubbles trapped in the ice at the time of its formation. As the figure shows, concentrations of the two greenhouse gases were consistently high when the climate was warm and low when the climate was cold.

Although the climatic changes shown in Figure 22.1 were largely initiated by variations in the Earth's orbit, changes in carbon dioxide and methane concentrations appear to have reinforced and amplified the initial fluctuations, thus exerting a powerful positive feedback effect. Variations in the concentrations of these gases would have occurred as the biosphere and oceans adapted to the initial climatic change and the alteration of seasonal sunlight caused by the change in orbit.

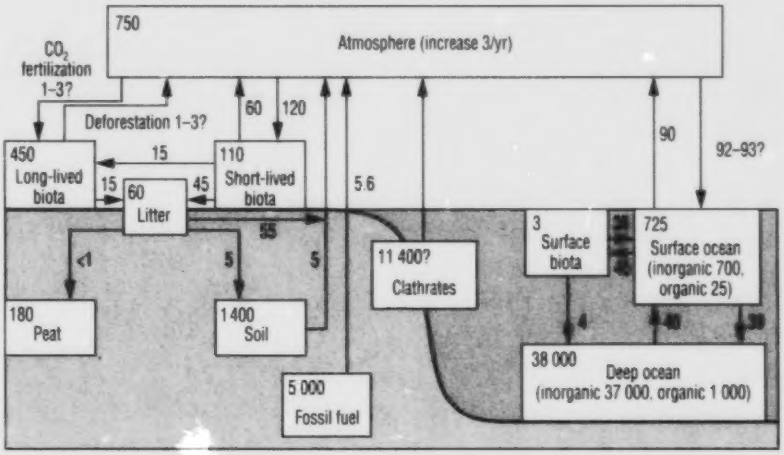
To understand why the biosphere and oceans play such an important part in this process, one must examine the carbon cycle. One of the unique features of this planet is that the element carbon, one of the principal building blocks of living matter, is continuously and rapidly exchanged between different reservoirs. One of these is the atmosphere, which acts as a transfer station for carbon as it is transferred in and out of the biosphere (by processes of photosynthesis and decay), to and from the ocean (by gaseous exchange), and in and out of the rocks of the Earth's crust (by weathering and volcanic degassing).

Figure 22.2 shows the carbon cycle and the various reservoirs. Each box represents a different reservoir, and the numbers indicate the mass of carbon, in billions of tonnes, that it contains. Arrows and numbers between boxes represent exchanges or fluxes of carbon in billions of tonnes per year.

FIGURE 22.2

The global carbon cycle

Numbers in boxes represent billions of tonnes of carbon, and numbers between boxes represent flows of carbon in billions of tonnes per year.



Source: MacDonald (1990).

The atmosphere contains about 750 billion tonnes of carbon in the form of carbon dioxide. Photosynthesis removes about 120 billion tonnes per year, but plant respiration and the decay of detritus and soil organic matter return about the same amount to the atmosphere. Living plants contain about 560 billion tonnes of carbon, and detritus and the world's soils contain about 1 400 billion tonnes. Canada is one of the world's significant carbon storage areas. It is estimated that about 35 billion tonnes of carbon are contained in the boreal forests, which cover 29% of the country. A further 100–150 billion tonnes occur in peat and muskeg deposits, much of it locked up in permafrost.

Globally, approximately 11 000 billion tonnes of carbon are contained in clathrates — complexes of water and methane molecules found in sediments beneath the oceanic continental shelf and in some onshore permafrost. The oceans, however, with 38 000 billion tonnes of carbon, are the largest reservoir and a major factor in the long-term concentration of carbon dioxide in the atmosphere.

Climatic change, by affecting such factors as the growth and death rates of plants and animals and the exchange of carbon dioxide between the oceans and the atmosphere, will cause the distribution of carbon among these various reservoirs to vary. Thus, the atmospheric concentration of carbon dioxide will fluctuate naturally as climatic conditions cause more of it to be drawn into the oceans or the biosphere or, alternatively, as more is released from these sources back into the atmosphere.

THE HUMAN IMPACT

Sources and levels of emissions

The natural carbon cycle is a closely balanced system. However, for the last 200 years human activities have been upsetting this balance. With the advent of the industrial revolution, humans began using massive and ever-increasing quantities of fossil fuels for

TABLE 22.1

The 10 nations with the highest releases of carbon dioxide from fossil fuel use in absolute terms and on a per capita basis

Data are for 1980–82 but have not changed substantially for the major carbon dioxide emitters shown here

Country	Absolute emissions (millions of tonnes of carbon per year)	Country	Per capita emissions (tonnes of carbon per year)
United States	1 135	East Germany	5.0
U.S.S.R.	901	United States	4.9
China	413	Canada	4.4
Japan	226	Czechoslovakia	4.2
West Germany	181	Australia	3.8
United Kingdom	141	U.S.S.R.	3.3
Poland	112	Belgium	3.3
France	110	Poland	3.1
Canada	108	West Germany	2.9
India	105	United Kingdom	2.5

Source: Rotty (1987) for fossil fuel emissions, United Nations (1990) for population data.

energy, thereby unlocking the vast quantities of carbon stored in these substances and releasing it to the atmosphere. At the same time, a rapidly expanding human population began to consume more of the world's forests as its demand for fuel, building materials, and, most of all, agricultural land grew. With the continuing depletion of the forests, further distortion of the natural carbon cycle has taken place.

The burning of fossil fuels (oil, gas, and coal) adds nearly 22 billion tonnes of carbon dioxide, or about 6 billion tonnes of carbon, to the atmosphere every year. Deforestation probably adds a further 1.6–2.7 billion tonnes of carbon (Houghton, 1991). These amounts might seem small in comparison to the large fluxes of the natural carbon cycle. However, long-term imbalances in fluxes to and from the atmosphere in the natural cycle generally amount to much less than 1 billion tonnes per year. Compared to this relatively small imbalance, the fluxes due to human activities are, in fact, quite large. As a result, humankind is radically altering what had been an almost perfectly balanced natural system.

Table 22.1 lists the 10 countries with the highest releases of carbon dioxide from fossil fuel use, in terms of total and per capita emissions. Canada, though responsible for only 2% of global emissions, has one of the highest per capita emission rates in the world — an estimated 4.4 t of carbon for every man, woman, and child in the country. Figure 22.3 shows how these emissions are distributed among different activities within the country.

Deforestation and associated biomass burning are also major sources of carbon dioxide, as well as being important sources of carbon monoxide, nitrous oxide, and other pollutants. The uncertainties associated with these emissions are much larger than those associated with fossil fuel use.

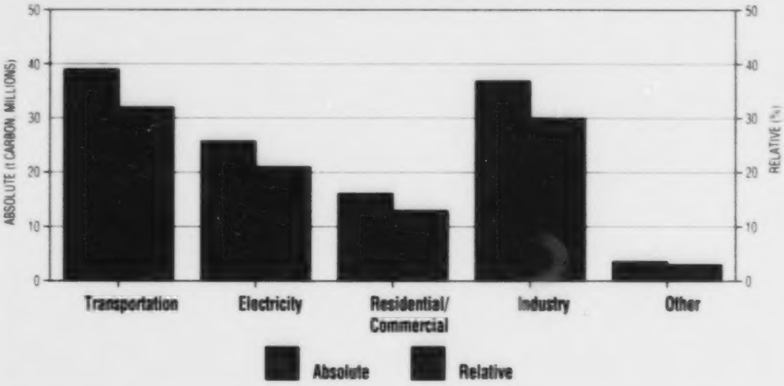
Of all the greenhouse gases being added to the atmosphere by human activity, carbon dioxide is the most important. It has been responsible for about 60% of the extra greenhouse effect so far and is likely to account for 50–75% of future increases in its intensity. Interestingly enough, other greenhouse gases are more powerful absorbers of infrared radiation than carbon dioxide, but because they exist in much smaller quantities in the atmosphere their overall impact is less. Methane, for example, traps 25–30 times more infrared radiation per molecule than does carbon dioxide. It exerts most of its effect on greenhouse warming during its relatively short atmospheric lifetime of about 10 years, but because methane is eventually converted to carbon dioxide it continues to contribute to the greenhouse effect long after its release.

Methane is formed when organic material decays in the absence of oxygen. Bogs and swamps are a major natural source of the gas, but significant amounts are also produced by insects, such as termites, and ruminant animals, such as sheep and cattle. Table 22.2 shows, however, that human-induced emissions appear to already exceed natural emissions. Although energy-related emissions are not insignificant, the greater part of these anthropogenic releases are the result of changing land uses — the expansion of rice paddies, grazing land for cattle, and landfill sites for waste disposal.

The human impact on the atmospheric abundance of carbon dioxide and methane can be seen by referring back to Figure 22.1. As the graph shows, throughout the enormous climatic oscillations of the past 160 000 years, concentrations of these gases remained within tight limits: between 180 and 290 ppm by volume (ppmv) for carbon dioxide and between 0.3 and 0.7 ppmv for methane. A little more than 200 years ago, however — a threshold that coincides with the beginnings of both the industrial revolution and a massive increase in human population — the concentrations of these gases began to rise rapidly and move beyond the boundaries of recent natural variability. Figure 22.4 shows the atmospheric concentration trends for carbon dioxide and methane from the mid-1700s to the present. By the late 1980s the carbon dioxide concentration had increased by 25% over preindustrial values, from 280 to 350 ppmv. During the same period, the methane concentration more than doubled, from 0.8 to 1.7 ppmv.

FIGURE 22.3

Absolute and relative contributions of transportation, electricity generation, residential/commercial fuel use, and industrial fuel use to carbon dioxide emissions within Canada



Source: Jaques (1990).

TABLE 22.2

Estimated global natural and human-induced emissions of methane

Source	Emission rate (billions of kilograms of carbon per year)
Anthropogenic	
Ruminants	65–100
Rice paddies	60–170
Biomass burning	50–100
Landfills	30–70
Coal mining	25–45
Natural gas flaring	25–50
Total anthropogenic	255–535
Natural	
Swamps and marshes	100–200
Lakes	1–25
Oceans	5–20
Total natural	106–245
Total	**361–780**

Source: Cicerone and Oremland (1988).

Other powerful greenhouse gases include the chlorofluorocarbons or CFCs (an entirely synthetic group of compounds), nitrous oxide, and ozone. CFCs have several thousand times more warming potential than carbon dioxide, although their atmospheric concentrations are relatively low. Because they threaten the ozone layer, their production is likely to cease by the end of the century. Nevertheless, their long atmospheric lifetimes will ensure that they continue to affect global warming for most of the next 100 years. Furthermore, it may also be impossible, at least initially, to replace all CFCs with compounds that are both less damaging to the ozone layer and transparent to infrared radiation. Some of the proposed substitutes, such as hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs), are still highly effective, though much shorter-lived, greenhouse gases (Fisher *et al.* 1990).

Nitrous oxide, perhaps best known as the "laughing gas" once used as a dental anaesthetic, is not as potent a greenhouse gas as the CFCs but is still several hundred times more powerful than carbon dioxide. It is produced naturally in soil and water, but, as Table 22.3 suggests, human-induced emissions — largely from agricultural fertilizers, fossil fuels, and the expansion of agricultural land — now account for about one-third of the releases of this gas.

Ozone is found primarily in the upper atmosphere where it forms the stratospheric ozone layer and absorbs ultraviolet radiation from the sun. A much smaller quantity is present in the lowermost atmosphere, the troposphere, where it is both a toxic pollutant and a greenhouse gas. Although some ozone is produced industrially, virtually all of the ozone in the troposphere is a natural by-product of a cycle involving chemical reactions with nitrogen oxides. In unpolluted air, ozone is quickly broken down through reaction with nitric oxide and other gases such as carbon monoxide. In air polluted with high concentrations of nitrogen oxides and volatile organic compounds, however, ozone is *created* by reaction with carbon-containing compounds. In the middle to high latitudes of the northern hemisphere, concentrations of tropospheric ozone have more than doubled during the past 100 years (Hough and Derwent 1990).

Carbon monoxide, though not itself a greenhouse gas, also contributes indirectly to the buildup of methane in the atmosphere. Methane is broken down primarily through reaction with the hydroxyl radical.[2] Because carbon monoxide also reacts readily with the hydroxyl radical, increased concentrations of carbon monoxide deplete the atmosphere of its most important methane sink. As Table 22.4 shows, most carbon monoxide emissions in Canada come from fossil fuel use, particularly in transportation. The carbon monoxide concentration in the northern hemisphere is estimated to have doubled since the start of the industrial revolution (Khalil and Rasmussen 1988*a*). This would have reduced the hydroxyl radical concentration by about 20%, thus increasing the atmospheric lifetime and concentration of methane. It has

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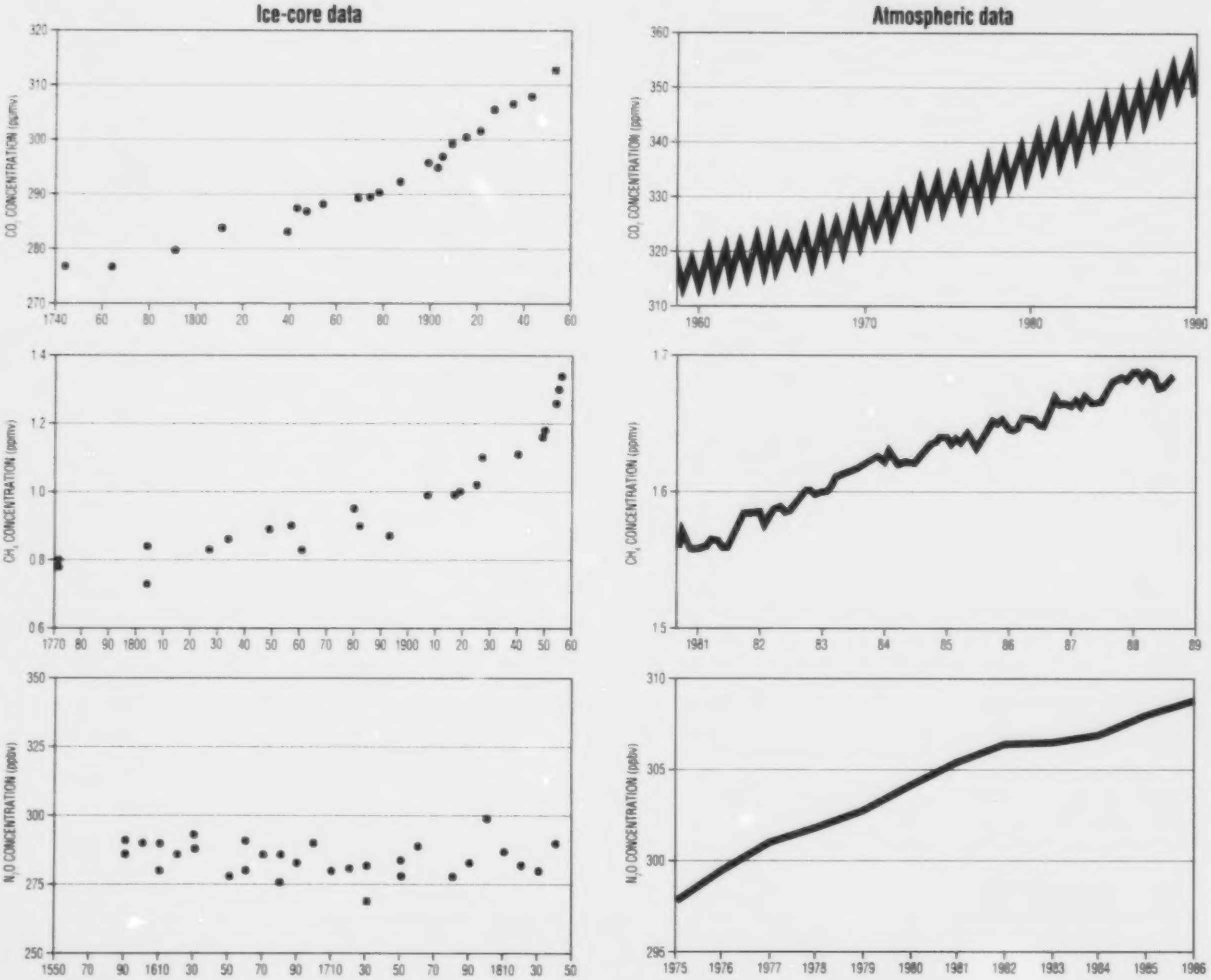
[2] A radical is a highly reactive fragment of a stable molecule. It differs from a reactive ion in that it does not have an electrical charge.

FIGURE 22.4

Variation of atmospheric carbon dioxide, methane, and nitrous oxide concentrations during the past 200–400 years



Source: Neftel *et al.* (1985); Bolle *et al.* (1986); Pearman *et al.* (1986); Khalil and Rasmussen (1988*b*); Boden *et al.* (1990).

been estimated that one-third of the atmospheric methane increase since the industrial revolution could have been caused by carbon monoxide emissions alone (Thompson and Cicerone 1986). In addition, carbon monoxide may also prolong the atmospheric lifetimes of the HCFCs and HFCs (the CFC substitutes), thus augmenting both their greenhouse effect and ozone-depleting potential.

If the world does nothing to limit its consumption of fossil fuels, global emissions, and, hence, atmospheric concentrations, of carbon dioxide are expected to grow dramatically during the coming decades. Under such a business-as-usual scenario, concentrations of other greenhouse gases — methane, nitrous oxide, and tropospheric ozone — would increase as well. Just how great these increases might be can be seen in Table 22.5. The table compares preindustrial and current concentrations of five key greenhouse gases and then projects what these concentrations would be in the year 2050 on the basis of two contrasting scenarios. The first of these assumes that no effort is made to restrict the buildup of these gases, the second, that aggressive policy measures are taken to limit their buildup.

In the absence of restrictions on fossil fuel use, how far could atmospheric levels of carbon dioxide be increased?

TABLE 22.3

Estimated global natural and human-induced emissions of nitrous oxide

Source	Emission rate (billions of kilograms of nitrogen per year)
Anthropogenic	
Fertilizer	0.6–3.0
Increase of cultivated land area	0.2–3.0
Fossil fuel burning	1–4
Biomass burning	1–2
Total anthropogenic	3–12
Natural	
Ocean/fresh water	1–9
Natural soils	6–13
Lightning	< 0.1
Total natural	7–22
Total	**10–34**

Source: Bolle *et al.* (1986).

TABLE 22.4

Sources of carbon monoxide emissions in Canada in 1985

Source	Absolute emissions (thousands of tonnes per year)	%
Light-duty vehicles	4 880	45.3
Medium-duty vehicles	567	5.3
Heavy-duty vehicles	436	4.0
Nonroad transport	250	2.3
Industrial engines	1 028	9.5
Fuel processing	62	0.6
Fuel combustion (nonelectric power)	1 208	11.2
Power generation	56	0.5
Industrial processes	713	6.6
Other	1 578	14.6
Total	**10 780**	**100.0**

Source: Kosteltz and Deslauriers (1990).

TABLE 22.5

Preindustrial, 1990, and projected 2050 atmospheric concentrations of carbon dioxide, methane, nitrous oxide, CFC-11, and CFC-12

Gas	Concentration			
			2050	
	Preindustrial	1990	Without restraints	With restraints
Carbon dioxide	280 ppmv[a]	356	450–600	400–450
Methane	0.7 ppmv	1.7	2.5–4.0	2.0–2.5
Nitrous oxide	0.29 ppmv	0.31	0.40–0.60	0.35–0.40
CFC-11	0.0 pptv[b]	270	450	390
CFC-12	0.0 pptv	458	830	480

[a] Parts per million by volume.

[b] Parts per trillion by volume.

Source: Harvey (1989).

TABLE 22.6

Estimated size of the planet's ultimately recoverable fossil fuel resources, and the increase in atmospheric carbon dioxide concentration that would occur if these resources were used and half of the emitted carbon dioxide remained in the atmosphere

Fuel	Recoverable resource[a] (billions of tonnes of carbon)	Atmospheric CO_2 increase (ppmv)
Conventional oil	230–380	54–89
Natural gas	140–230	33–54
Coal	3 500–6 300	817–1 470
Tar sands	75–200	18–47
Oil shales	170–9 500	40–2 220
Total	**4 115–16 610**	**962–3 880**

[a] The quantity of fossil fuels in the ground is even larger than indicated, but much is not worth extracting either because the quality is too low or because more energy would be required to extract it than it would supply. Determination of what is ultimately recoverable is highly subjective, and various estimates differ greatly. The values presented are merely illustrative.

Source: Rotty and Marland (1980).

An upper limit to this increase can be derived from an estimate of the quantity of fossil fuel resources that are ultimately recoverable. This is given for different fossil fuels in Table 22.6, and it indicates that the atmospheric carbon dioxide concentration could eventually reach 5–10 times the preindustrial concentration of 280 ppm.[3] If the heating effect of increases in other greenhouse gases is included, the total effect would be equivalent to even larger carbon dioxide increases.

With present levels of the major greenhouse gases already significantly above the highest levels of the past 160 000 years, it is reasonable to ask whether they have already had a measurable impact on global temperature. Figure 22.5, which plots the variation of the world's average surface air temperature since 1861, shows a warming of about 0.5°C during the past 85 years (Jones and Wigley 1990). However, a variety of indicators suggest that, during the last 1 000 years, global temperatures have fluctuated naturally by perhaps 1°C. Because the current warming falls within this range, it cannot be proven that it was caused by the buildup of greenhouse gases. Nevertheless, it is consistent with the effects expected from such a buildup.

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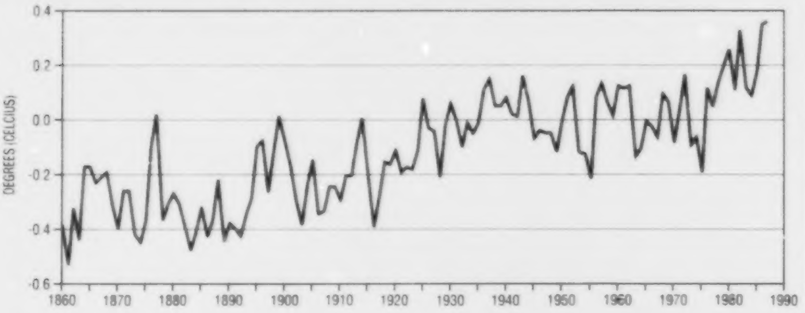
[3] This estimate assumes that half of the emitted carbon dioxide would remain in the atmosphere. For exponentially increasing emissions, this is a valid first approximation.

FIGURE 22.5

Variation of global mean surface air temperature since 1861

Values shown are departures of annual means from 1950–79 reference period mean.



Source: Jones and Wigley (1990).

Human-induced increases in greenhouse gases have thus far had as much heating effect on the world's climate as a 0.8% increase in solar energy. By 2050, this effect could be several times greater.[4] In contrast, the energy output of the sun has been remarkably constant. It appears to have varied with the 11-year sunspot cycle by no more than 0.1% during the past 120 years (Foukal and Lean 1990). For this and other reasons, the effect of increasing greenhouse gas concentrations is expected to swamp natural climatic variations during the next century, leading to a long-term warming of the climate.

Future climate

To anticipate the consequences of such unprecedented greenhouse gas concentrations, scientists have turned to computer-based, mathematical models of the climate system. The most advanced versions are exceptionally complex; even the world's most powerful supercomputers can take 1 000 hours or more to make all the calculations that go into one of these simulations. Yet they are based on a simple premise: climatic processes are the product of fundamental laws of physics and chemistry and can therefore be reconstructed mathematically through the equations that express these laws.

However, the climate system itself is so complex that even the most elaborate models can as yet give only a very simplified rendering of its operation. Nevertheless, models are extremely useful for examining processes, such as climatic change, that cannot be studied experimentally in nature or in the laboratory. Models have been used extensively in the atmospheric sciences since the advent of electronic computers in the late 1940s, and they have become increasingly effective over the years, as modelling techniques, computer power, and knowledge of the climate system have expanded.

The most sophisticated models in use today are three-dimensional atmospheric general circulation models, or AGCMs, which are coupled to oceanic models of varying complexity. These models divide the atmosphere into several thousand grid boxes. Each box covers an area of the Earth's surface measuring anywhere from 200 by 200 km to 500 by 500 km horizontally and contains 2–20 layers vertically. The models simulate such variables as wind, temperature, cloud, precipitation, soil moisture, and the extent of ice and snow, and they are able to simulate day-to-day changes in climate likely for each scenario.

Two approaches have been used in modelling future climatic change. The first generally uses simple models to simulate the gradual but continuous warming of climate in response to a gradual buildup of greenhouse gases, taking into account the uncertain lag effect due to the storage of heat in the cold oceans. The second generally uses the more complex AGCMs to simulate the response of various climatic variables, such as temperature and precipitation, to a sudden doubling of carbon dioxide in the atmosphere.

The sensitivity of a climatic variable to a given greenhouse gas increase depends not only on the radiative heating effect of the gas, which is relatively well known, but also on various climatic feedback processes. One of the most important of these is the increase of atmospheric water vapour that accompanies climatic warming. Because water vapour is itself a strong greenhouse gas, this increase contributes to further warming. The various models are in close agreement with each other and with observational evidence regarding the strength of this feedback (Raval and Ramanathan 1989).

One of the major disagreements among models, however, concerns the net effect of cloud feedbacks. The problem arises because clouds not only reflect incoming solar radiation (thus making the Earth cooler) but also trap outgoing infrared radiation (thus making it warmer). A small change in either of these effects, therefore, will cause a large change in temperature. The difficulty of predicting changes in the extent and nature of cloud cover introduces further uncertainties into computations of these feedbacks. These uncertainties are unlikely to be reduced in the near future.

There are a number of other potential feedbacks, both positive and negative, that the models have been unable to take into account because it is not possible at the present time to quantify them. In particular, increased warming could trigger a number of responses within the carbon cycle that could significantly alter the amount and rate of warming.

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[4] The human-induced heating effect so far is about 2.0 W/m^2 averaged over the entire globe and could reach 5–10 W/m^2 by 2050 based on Harvey (1989). A 1% increase in energy from the sun would increase the globally averaged absorbed solar energy by 2.4 W/m^2.

Warmer temperatures, for example, cause plants and soils to emit more carbon dioxide through respiration. Because the flux from this source is very large — about 120 billion tonnes of carbon per year — an increase of only a few percent in natural emissions from respiration would be comparable to all of the current flux from fossil fuel burning. The thawing and draining of permafrost would also allow the oxidation of enormous stores of carbon. Further large fluxes could arise if forests that are adapted to present climatic regimes died back at a faster rate than they could be replaced by the migration of different tree species. Significant quantities of methane now stored in clathrates could also be added to the atmosphere as a result of the thawing of terrestrial permafrost and the warming of continental shelf sediments in the Arctic Ocean. All of these releases would act as positive feedbacks and would accelerate the warming of the climate.

Opposing these positive feedbacks is the tendency for higher atmospheric carbon dioxide concentrations to stimulate greater rates of photosynthesis in plants. This causes the plants to remove more carbon dioxide from the atmosphere and thus acts as a negative feedback to slow the rate of carbon dioxide increase. Indeed, there is growing evidence that the world's remaining healthy forests are already absorbing up to one-third of the carbon dioxide emitted from the burning of fossil fuels (Tans *et al.* 1990). However, as both temperatures and carbon dioxide levels increase, plants could release more carbon dioxide through respiration than they take up through photosynthesis (Harvey, 1991). The world's forests would then become net emitters of carbon dioxide rather than net absorbers.

TABLE 22.7

Average temperature increase of air at the Earth's surface if levels of carbon dioxide double over levels in preindustrial times, as projected by different modelling groups

Model	Global mean annual surface air warming (°C)	Reference
Canadian Climate Centre	3.5	G. Boer, Environment Canada, personal communication
Goddard Institute for Space Studies	4.2	Hansen *et al.* (1984)
Geophysical Fluid Dynamics Laboratory	4.0	Wetherald and Manabe (1988)
National Center for Atmospheric Research	3.5	Washington and Meehl (1984)
United Kingdom Meteorological Office	5.2	Wilson and Mitchell (1987)
	1.9	Mitchell *et al.* (1989)
	2.5	best current estimate, J.F.B. Mitchell, United Kingdom Meteorological Office, personal communication

Table 22.7 summarizes the values given by various models for the change in global mean surface air temperature that would result from a fixed doubling of carbon dioxide over preindustrial levels. The predicted warming varies from 1.9°C to 5.2°C. The wide spread in the results is largely due to differences in the calculation of net cloud feedbacks. If the aforementioned carbon cycle feedbacks release further carbon dioxide to the atmosphere, then the ultimate effect of a human-induced doubling of carbon dioxide would be even larger.

Increases in global temperature will not be distributed uniformly either regionally or seasonally. Figure 22.6 compares the values calculated using four different AGCMs for changes in winter temperature in Canada as a result of carbon dioxide doubling. Figure 22.7 shows the same thing for summer. These models predict a similar globally and annually averaged warming — from 3.5°C to 4.2°C — and all of them predict greater year-round warming at high latitudes and greater warming in winter than in summer at middle to high latitudes. However, as Figures 22.6 and 22.7 reveal, the models disagree substantially on the effects for any given region.

All climate models agree that, as climate warms, both the global mean evaporation and precipitation must increase. However, precipitation will not increase everywhere. As the climate system adjusts, precipitation belts will shift, and precipitation in some regions will actually decrease. Even where precipitation increases, soils in some regions will become drier in summer as a result of increased evaporation. Overall, the models predict an increase in average annual precipitation in high latitudes and a decrease in mid-latitudes (30–50°C) in both hemispheres, although winter precipitation in the mid-latitudes is generally predicted to increase. However, as can be seen from Figure 22.8, the models disagree on how all of this affects net soil moisture in any given region.

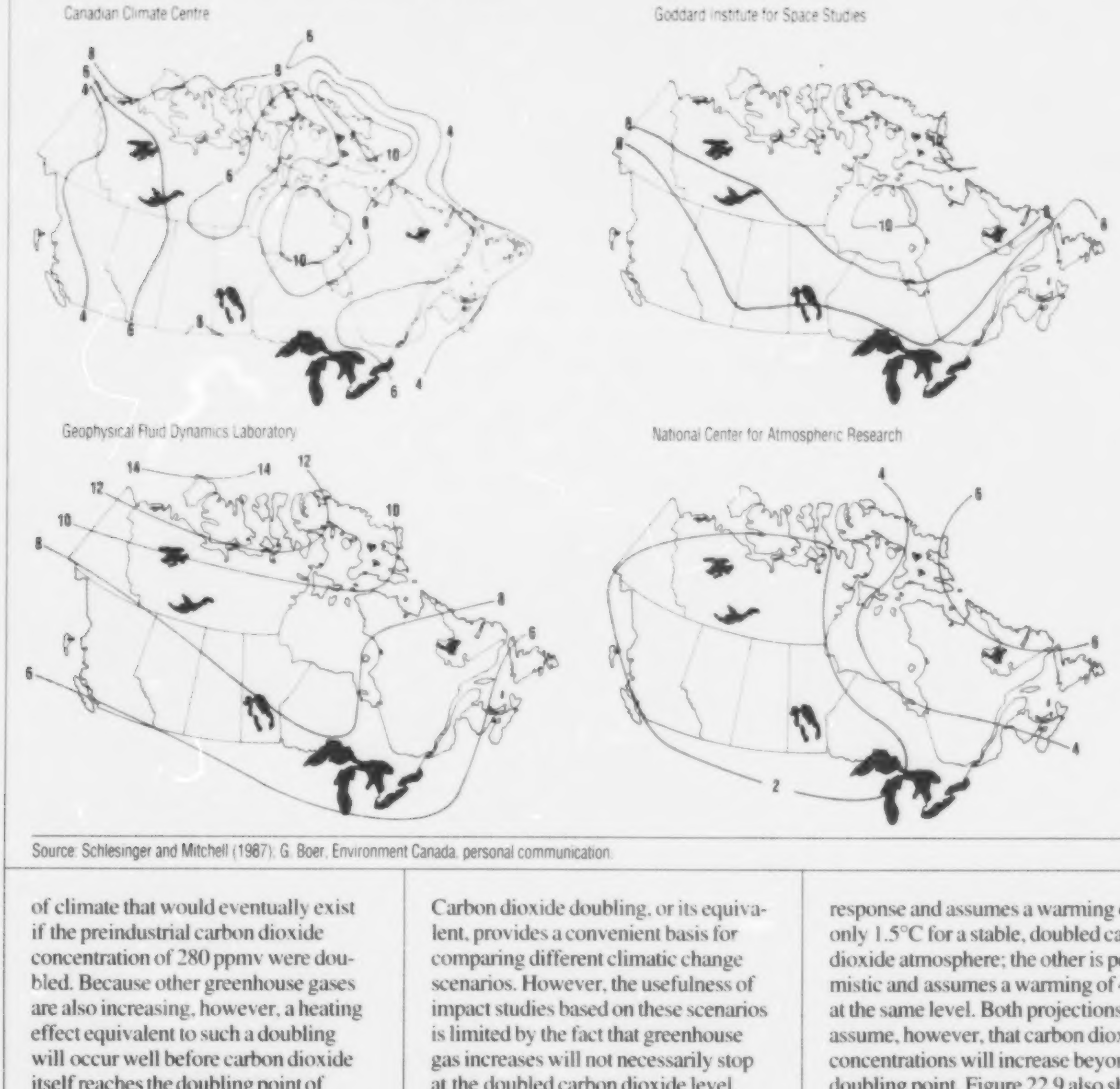
But, as important as these changes in climatic averages are, changes in climatic variability may have even greater significance. Some model results, as well as comparisons of sequences of warm and cold years in the Canadian climate records, indicate that a warming of the climate will decrease the variability of temperature but increase the variability of precipitation (Brown and Walsh 1986; Rind 1991). Under such conditions extreme drought years could occur more frequently, even with an increase in average rainfall.

ASSESSING THE IMPACT

A number of studies have been done to date on the impacts of climatic change resulting from increases in greenhouse gases. Almost all of these have been based on model forecasts of the type

FIGURE 22.6

Change in winter temperatures in degrees Celsius over Canada for carbon dioxide doubling, as predicted by four different modelling groups



Canadian Climate Centre

Goddard Institute for Space Studies

Geophysical Fluid Dynamics Laboratory

National Center for Atmospheric Research

Source: Schlesinger and Mitchell (1987); G. Boer, Environment Canada, personal communication.

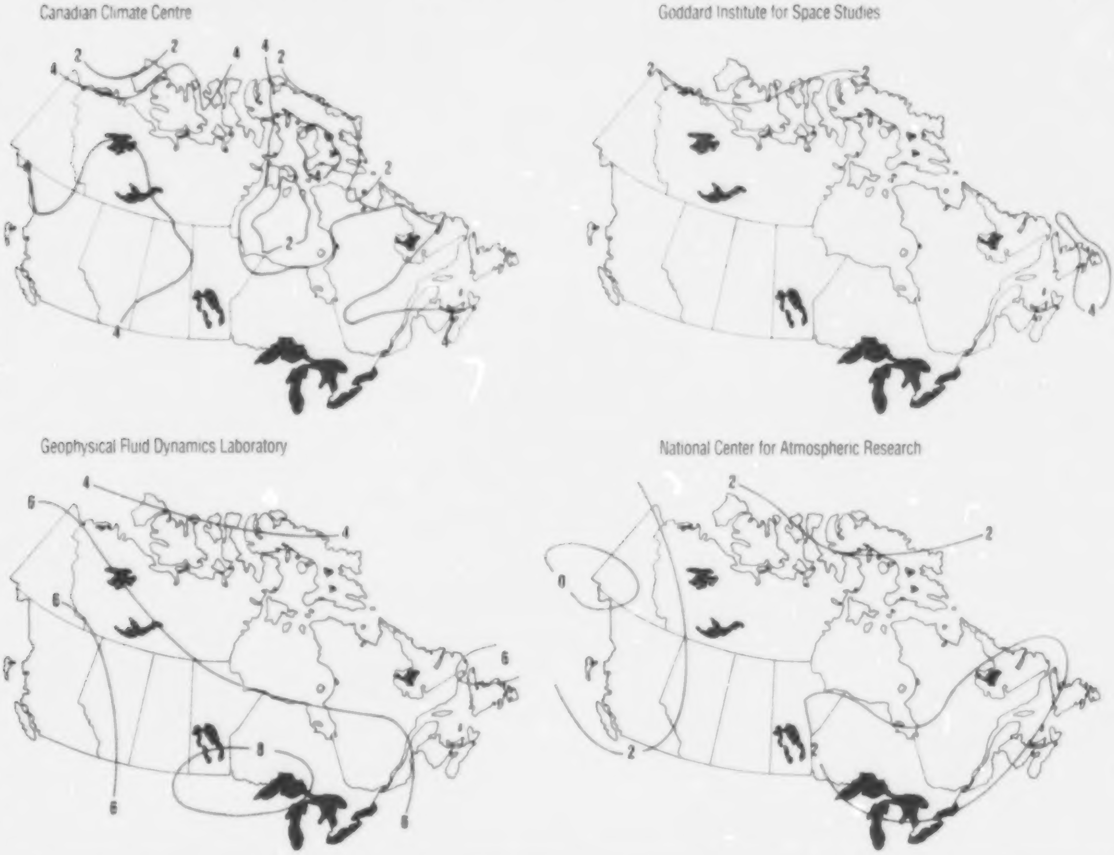
of climate that would eventually exist if the preindustrial carbon dioxide concentration of 280 ppmv were doubled. Because other greenhouse gases are also increasing, however, a heating effect equivalent to such a doubling will occur well before carbon dioxide itself reaches the doubling point of 560 ppmv. This equivalent could be achieved by the time carbon dioxide reaches 450 ppmv (Harvey 1990). This could occur as early as 2025, although the climatic response would lag by one to several decades because of the slow warming of the oceans.

Carbon dioxide doubling, or its equivalent, provides a convenient basis for comparing different climatic change scenarios. However, the usefulness of impact studies based on these scenarios is limited by the fact that greenhouse gas increases will not necessarily stop at the doubled carbon dioxide level. Indeed, they will significantly surpass this benchmark if we continue with business-as-usual emission practices. Climatic change would then shoot far beyond the levels projected for a doubled carbon dioxide atmosphere.

Figure 22.9, for example, shows two projected globally averaged warming trends for a business-as-usual scenario. One is optimistic about the net climatic response and assumes a warming of only 1.5°C for a stable, doubled carbon dioxide atmosphere; the other is pessimistic and assumes a warming of 4.5°C at the same level. Both projections assume, however, that carbon dioxide concentrations will increase beyond the doubling point. Figure 22.9 also shows the last time when the Earth's climate reached the temperatures shown on the graph. To find the nearest precedent for the kind of climate this planet could experience within the next century, we would have to search nearly 40 million years into the geological past. Admittedly, this is a worst-case projection,

FIGURE 22.7

Change in summer temperatures in degrees Celsius over Canada for carbon dioxide doubling, as predicted by four different modelling groups



Canadian Climate Centre

Goddard Institute for Space Studies

Geophysical Fluid Dynamics Laboratory

National Center for Atmospheric Research

Source: Schlesinger and Mitchell (1987); G. Boer, Environment Canada, personal communication.

but it is a useful reminder that carbon dioxide doubling, which forms the basis of all impact studies to date, is only one point on a continuum of open-ended climatic change.

In interpreting the impact studies outlined in the following pages, two other considerations should be kept in mind. The first is that greenhouse gas concentrations in the real world will change continuously and different regions will warm at different rates. Doubled carbon dioxide simulations, on the other hand, describe an atmosphere whose processes are in balance with a fixed, though elevated, concentration of greenhouse gases. As a result, the patterns of temperature change that occur in reality are likely to differ from those derived from the models. Similarly, precipitation and soil moisture patterns during transitional climates could be completely different from those of a balanced climate.

The second consideration is that, in many instances, the rate of climatic change is more important than the change itself. This is particularly true for forest ecosystems, where potentially beneficial changes could have severe impacts if they were to occur more rapidly than forests can migrate.

None of the climatic simulations upon which impact studies are based should be regarded as predictions of the future. Rather, they are scenarios: simplified but internally consistent simulations that indicate a range of possible futures.

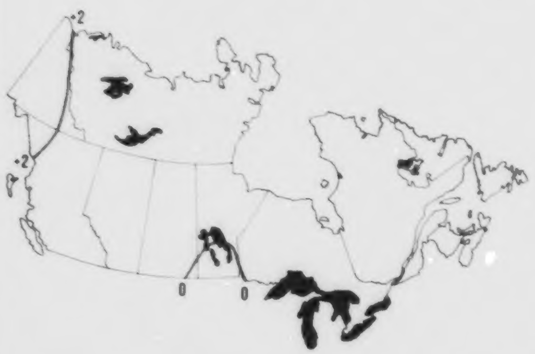
Ecoclimatic provinces

Because most species survive within a fairly narrow set of climatic limits, climate exerts a strong influence on the distribution of terrestrial ecosystems. This relationship can be translated into the idea of ecoclimatic provinces, or broad landscapes in which there is a fundamentally similar ecological response to climate.

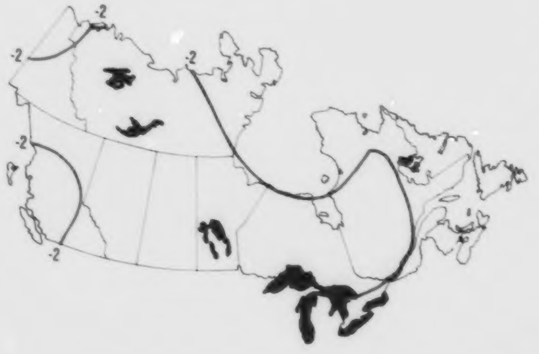
FIGURE 22.8

Change in summer soil moisture in Canada for carbon dioxide doubling, as simulated by six different modelling groups

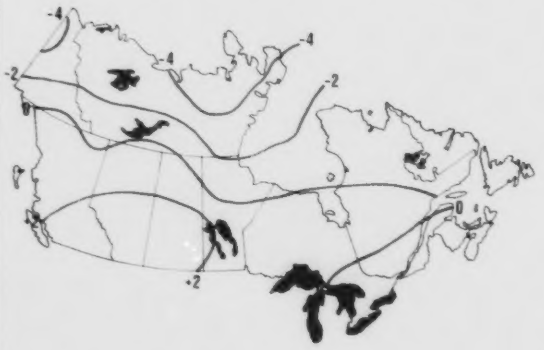
With the exception of the Canadian Climate Centre model, these maps show change in soil moisture, expressed as centimetres of water. The Canadian Climate Centre model expresses change as a percentage of soil moisture capacity.



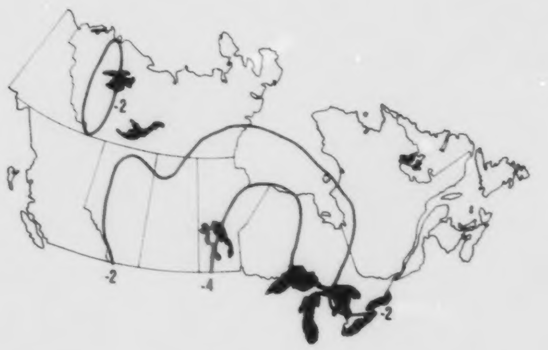
National Center for Atmospheric Research



Geophysical Fluid Dynamics Laboratory

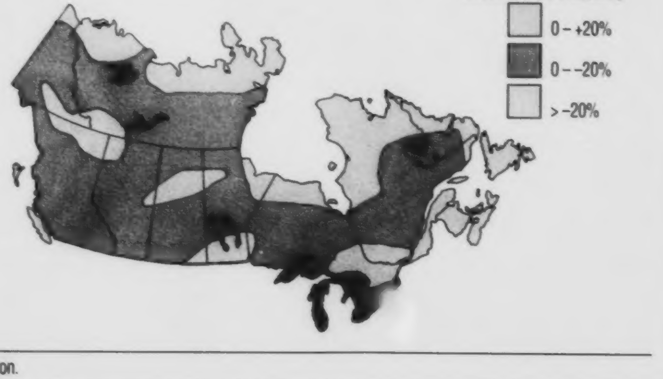


Goddard Institute for Space Studies



United Kingdom Meteorological Office

Oregon State University: decline in soil moisture of 0 to 2 cm everywhere



Canadian Climate Centre

Change in soil moisture as % of soil moisture capacity
0 – +20%
0 – –20%
> –20%

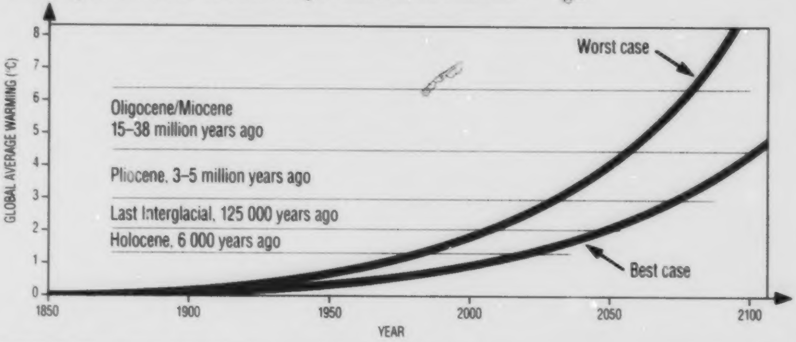
Source: Kellogg and Zhao (1988); G. Boer, Environment Canada, personal communication.

Figure 22.10 compares the present-day distribution of ecoclimatic provinces in Canada with the distribution that might occur under a doubled carbon dioxide climate as projected by one AGCM. The differences are striking. The currently warmest provinces (grassland, cool temperate, and moderate temperate) increase in size at the expense of the coldest (arctic, subarctic, and boreal).

The changes shown in Figure 22.10 are associated with greenhouse gas increases equivalent to a carbon dioxide doubling. Greater increases in greenhouse gases, which are assured under business-as-usual scenarios, would cause even greater alteration of the ecological landscape. Moreover, the changes projected in Figure 22.10 do not take into account the rate of climatic change. The equivalent of a carbon dioxide doubling could occur as soon as 2025 and the associated climatic conditions as soon as 2035, but forest ecosystems cannot migrate that quickly. Finally, these maps show the rearrangement of the different ecological zones on the basis of climate alone. Other factors, such as poor soils, would also limit the extent to which existing vegetation communities could relocate.

FIGURE 22.9

Globally averaged temperature change under business-as-usual scenarios, predicted using climate models that calculate best- and worst-case responses to a doubling of carbon dioxide in the atmosphere over levels in preindustrial times



Source: Krause *et al.* (1989).

Agriculture

Climatic warming could both enhance and hinder Canadian agriculture. Although longer and warmer growing seasons will tend to increase crop yields, moisture shortages or warming beyond ideal temperatures will reduce them. Increased evaporation resulting from warmer temperatures will cause soils to become drier if sufficiently large precipitation increases do not occur. Moreover, greater climatic variability could also increase the likelihood of drought. In Saskatchewan, for example, studies suggest that the average length of time between severe droughts could be halved, even with an increase in precipitation (Williams *et al.* 1988).

For Ontario, climatic models generally predict an increase in precipitation but differ about the amount. The current growing season of 160 days in the agricultural heartland of southern Ontario would increase to more than 200 days, but yields of many crops could decrease because of soil moisture shortages and excessive temperatures. Corn and soybeans, for example, would become risky, although they could become viable in parts of northern Ontario as a consequence of longer growing seasons. The climate in southern Ontario, however, could become much more favourable for the growth of apples and tender fruits, and much of the region could become a fruit belt (Smit 1987).

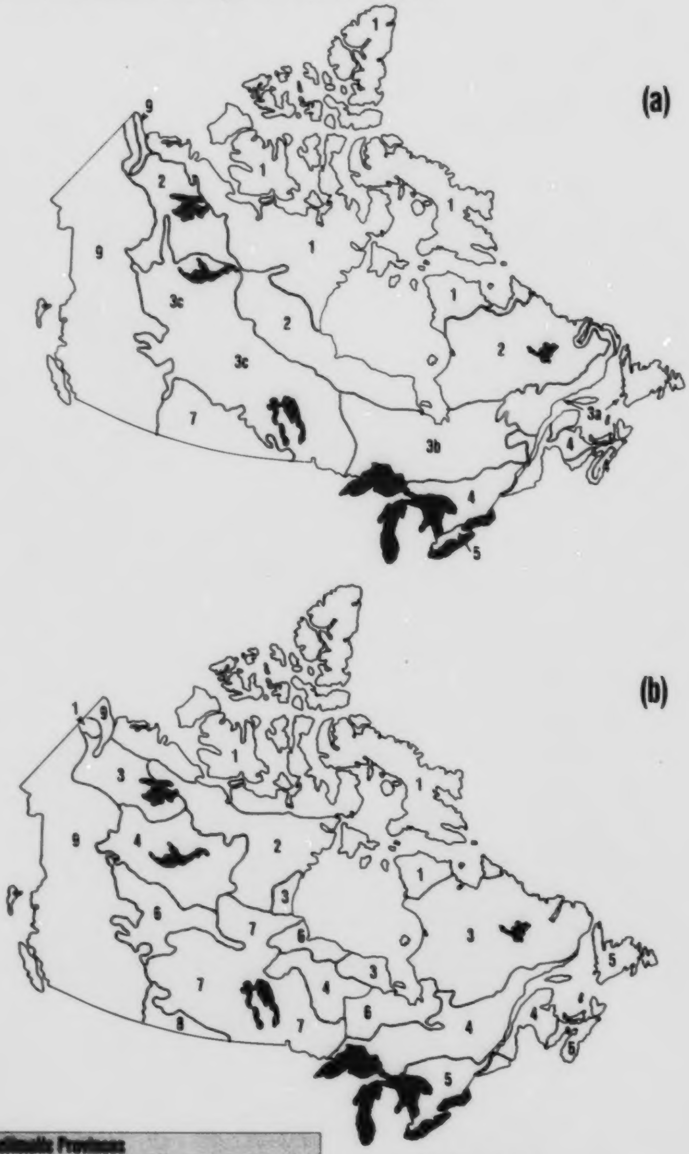
In the Prairie provinces, it is anticipated that greater evaporation would lead to reduced soil moisture in many areas and a significant decrease in crop yields. Changes in cropping practices, however, such as the substitution of winter wheat for spring wheat, could restore yields to current levels. It is also probable that drier conditions in the south could be offset by substantially improved climatic conditions in the north, though there are limits to how far northern expansion could compensate for lost agricultural productivity in the south. Much of the land that became available in the northern prairies would be suitable only for forage production (Arthur 1988).

The studies performed to date do not take into account certain physiological effects that higher carbon dioxide concentrations have on plants, notably increased photosynthesis and greater efficiency in the use of water. Nor do they consider a wide variety of human adaptive responses such as irrigation, dry farming techniques, or changes in crop varieties that could partly or largely mitigate the negative impacts of climatic warming and enhance the benefits. On the other hand, adaptation will compel individual farmers to make difficult decisions in the face of great uncertainty. These could involve issues ranging from changing crops or cropping practices to abandoning the land altogether.

Impact studies suggest that the climatic change associated with an equivalent carbon dioxide doubling will have only a small net effect on overall Canadian or provincial agricultural production when averaged over several years. Nevertheless, some localities will be more severely affected than others, especially during drought years, and some human dislocation may result. Moreover, if precipitation increases are not as large as projected, the negative impacts could be much more severe and widespread.

FIGURE 22.10

Distribution of ecoclimatic provinces in Canada: (a) present day; (b) as projected for a doubling of atmospheric carbon dioxide using the Goddard Institute for Space Studies model



Ecoclimatic Provinces			
1	Arctic	4	Cool Temperate
2	Subarctic	5	Moderate Temperate
3	Boreal	6	Transitional Grassland
	3a Maritime Boreal	7	Grassland
	3b Moist Continental Boreal	8	Semi-Desert
	3c Dry Continental Boreal	9	Unclassed, Cordilleras not shown

Source: Rizzo and Wiken (1989).

Forests

Forestry is one of the most important sectors of the Canadian economy, accounting for 17% of all Canadian exports and directly or indirectly employing 1 out of every 15 Canadian workers (Forestry Canada 1990). As Figure 22.10 suggests, it is also an industry whose natural base would be profoundly affected by the climatic change that would follow even an equivalent doubling of carbon dioxide. Much of the area now covered by boreal forest in western Canada would have a climate able to support only grassland or transitional forest–grassland ecosystems. The southern limit of the Boreal Ecoclimatic Province would be displaced northward by as much as 1 100 km and the northern limit by as much as 800 km. Similarly, the Cool Temperate Ecoclimatic Province in eastern Canada would be displaced as much as 500 km northward.

Since a doubled carbon dioxide climate could exist as early as 2035 if steps to stabilize greenhouse gas concentrations are not taken, today's forests would have to migrate at rates of 100–200 km per decade to survive intact. This is far in excess of natural rates of migration, which are in the order of 20–50 km per century (Davis 1989). Consequently, it is likely that trees will die back along the southern margins of forests in response to heat and/or moisture stress and be replaced with "weedy" trees that are good at migrating and colonizing (Solomon 1986). The result is likely to be a significant impoverishment of our forests.

Other factors will compound these stresses. Insect pests, for example, are likely to migrate more rapidly than trees, thus exposing forests to new species of pests. Because the predators of these pests might not be able to migrate as quickly, outbreaks of insect infestations might occur, not unlike those resulting from the accidental introduction of foreign insects into new areas. It is likely, too, that fires will become more frequent and more severe as a result of increased drought and a greater supply of dead wood. On the positive side, however, the removal of maladapted forests by fires will hasten their replacement by species better suited to the changing climate. Nevertheless, the ecological imbalance could last for several centuries.

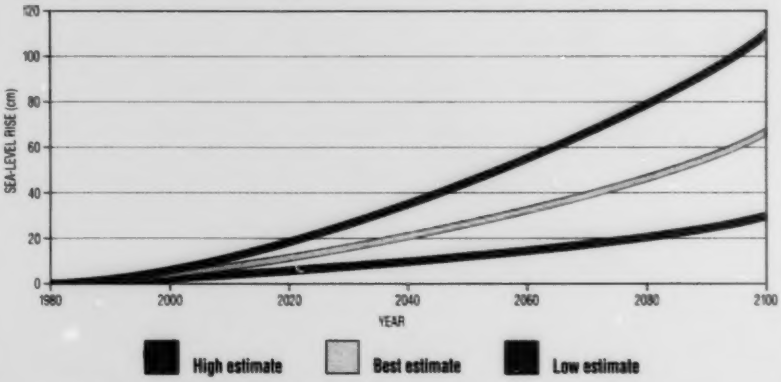
Although forestry agencies may try to accelerate migration through tree-planting programs, they will still face serious management problems, because by the time the trees mature the climate may no longer be suited to the species that had been planted. In addition, genetic adaptation to latitudinal changes in the amount of sunlight might not occur fast enough to match the rates of migration required by rapid climatic change. Such uncertainties might reduce investment in the forest industry and further intensify the problems of adaptation.

Trees, like agricultural crops, are likely to use water more efficiently when the atmosphere contains more carbon dioxide. This, in turn, could reduce the impact of reduced soil moisture. The magnitude of this effect, however, is extremely uncertain, as the only experiments to date were performed on seedlings. It is not known how mature trees or trees exposed to higher concentrations of carbon dioxide throughout their lives will respond.

Even with aggressive global measures to reduce greenhouse gas emissions, climatic change at rates exceeding the migration capabilities of forests is probable. The extent of forest dieback in response to this change is likely to depend strongly on the extent to which forests are already stressed by acidic deposition and ground-level ozone. Consequently, any strategy to safeguard Canada's forests must include dramatic reductions in emissions that cause acidic deposition and ozone formation, as well as global action to stabilize concentrations of greenhouse gases.

FIGURE 22.11

Projected mean global sea-level rise if nothing is done to reduce emissions of greenhouse gases



Source: Intergovernmental Panel on Climate Change (1990).

Rise in sea level

With the warming of the world's oceans, sea level will rise. At first this will largely be the result of the thermal expansion of seawater, but the melting of ice masses will have an increasing effect over time. Most analysts project an eventual sea-level rise of 0.5–1.0 m as a consequence of carbon dioxide doubling. Recent estimates, however, suggest that increasing snowfall in Antarctica might partially offset melting elsewhere and lead to a rise of only 0.3 m. This does not mean that a larger rise is no longer a threat. It merely means that it might take longer to occur, unless greenhouse gases are stabilized at a level no greater than an equivalent doubling of carbon dioxide. Without stabilization, a sea-level rise of 5–6 m or more could occur over the next several hundred years (Hekstra 1986). Figure 22.11 illustrates current estimates of sea-level rise during the next century.

Although sea levels are largely determined by the volume of seawater, they are affected by other factors as well. For that reason, they will not rise uniformly around the world. Many land areas, for example, are still rebounding from deglaciation. Others are subsiding. Parts of the Hudson Bay coast are currently emerging at up to 0.5 m per century, thus more or less offsetting the general rise in sea level. The coast around Halifax, on the other hand, is submerging at about 0.4 m per century, thus accentuating any sea-level rise due to global warming (Egginton and Andrews 1989).

Ocean currents also cause substantial regional variations in sea level. Between the western and eastern edges of the Gulf Stream off Florida, for example, there is a natural rise of about 1.4 m. Future variations in sea level as a result of ocean currents are difficult to predict because of uncertainties about how the currents will be affected by climatic changes.

A sea-level rise of as little as 1 m would directly or indirectly displace hundreds of millions of people worldwide. Such a catastrophe, coupled with reduced agricultural production in some parts of the world, could dramatically increase the number of refugees seeking entry into Canada.

Because Canada has the longest coastline of any country in the world, a 0.5- to 1-m rise in sea level would be very costly for a number of Canadian communities as well. Apart from the

BOX 22.1

If the sea rose 1 m at Charlottetown...

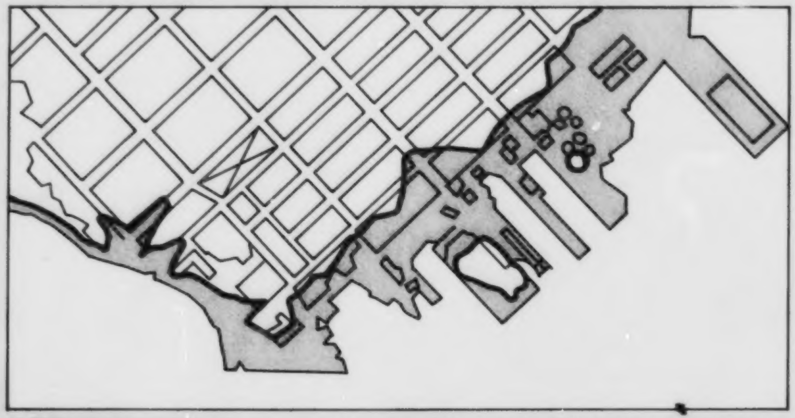
A recent study (Lane and Associates 1988) indicates that, as a result of a 1-m rise in sea level:

- portions of several streets in the city would be below high tide or subject to flooding during storms (Fig. 22.B1);
- the city's new harbourfront development would flood at high tide;
- about 225 buildings in the city could become uninhabitable because of periodic flooding from storm surges;
- access to the main marine terminal and coastguard docks would be severed by storm tides;
- the sewage treatment plant would not work during storms, and water backing up in storm sewers would cause flooding in parts of the city not adjacent to the coast;
- an increase in groundwater levels would reduce land drainage and adversely affect agricultural crops in the Charlottetown region.

FIGURE 22.B1

A 1-m rise in sea level would seriously increase the flood threat to areas near Charlottetown's waterfront

Major floods, which could be expected once every 20 years, would inundate the area indicated by the black line.



Source: Hengeveld (1991).

inundation of waterfront areas of coastal towns and cities (see Box 22.1), many other impacts would be felt. Shorelines would be subject to increased erosion as beaches receded. Storm surges (huge domes of water created by high winds and low pressures in violent storms) would become more destructive when superimposed upon a higher mean sea level. Sewage treatment plants, drainage systems, and freshwater supply systems would be threatened in many coastal areas by rising saltwater levels. Sediment transport and deposition in many rivers would also be altered as seawater penetrated further upstream.

A 1-m sea-level rise would lead to significant losses of coastal wetlands. These areas play important ecological roles and often provide a home for migratory bird sanctuaries and national wildlife reserves. Coastal wetlands occur in a number of large estuaries along the Pacific coast, along the western edge of Hudson Bay and the islands of the Foxe Basin in the Arctic, in the Mackenzie delta, and in a number of Atlantic estuaries and bays. To the south, coastal wetlands of the U.S. Gulf and Atlantic coasts serve as wintering grounds for many species of Canadian waterfowl. Here, obstacles constructed by people impeding the inland migration of wetlands could lead to particularly large habitat losses.

Marine fisheries

Marine fisheries will be affected by geographical shifts in the distribution of fish species caused by changes in water temperature and current patterns as well as by changes in the availability of nutrients. The abundance of commercially valuable fish stocks depends ultimately on the productivity of plants — mostly single-celled phytoplankton — at the base of the marine food chain. Over much of the world oceans, the productivity of these plants is limited by the availability of nutrients, whose distribution near the surface depends largely on the upwelling of nutrient-rich water from the ocean depths.

Upwelling is influenced by wind patterns, but, with global warming, winds in middle to high latitudes could become weaker as temperature differences between tropical and polar latitudes diminish. This, in turn, would lead to a more sluggish oceanic circulation with less upwelling and cause a global decrease in marine biological productivity. In high latitudes the melting of glacial ice and a likely increase in precipitation will increase continental runoff. Combined with increased summer melting of sea ice, this could lead to a more stable stratification of high-latitude oceans and restrict the upward mixing of nutrients.

The possibility of changes in nutrient upwelling poses a risk of decreased yields for both global and Canadian fisheries. Even if the average annual productivity of these primary food sources does not change, it is likely that their seasonal distribution will. This, too, would have profound effects on the rest of the marine ecosystem.

Fish migration routes and productivity are also sensitive to variations in the ocean's surface temperature. On the Pacific coast, it is estimated that a 3–4°C rise in water temperature could cause herring stocks to retreat northwards and be replaced by smaller and shorter-lived herring from farther south (Murty and Bernard 1985). As the current decline of the east coast haddock and cod fisheries shows, the decrease of even a few species in Canadian waters can be the cause of much economic hardship and social despair.

Fresh water

With climatic warming, precipitation is expected to increase in many areas, but evaporation rates will increase too. If the additional precipitation results from an increase in the intensity of storms (such as convective thunderstorms), a greater proportion of the rainfall will be lost as quick-response runoff. This means that less will be available for recharging soil moisture and replenishing the groundwater that supplies river flow between storms.

Other factors, some of which are difficult to quantify at this point, will affect the net water balance. What, for example, will be the effect of the physiological response of plants to a hotter climate? Although warmer temperatures tend to increase evapotranspiration (i.e., evaporation and transpiration) from plants, higher levels of carbon dioxide tend to decrease it. These opposing tendencies could neutralize each other and perhaps leave more water in the ground for recharging streamflow. This possibility has not yet been incorporated into assessments of the hydrologic impacts of climatic warming.

In western Canada the accumulation of winter snow in the high mountains is particularly important to spring and summer water supplies. In a warmer climate, winter precipitation is expected to increase, but relatively less precipitation will fall as snow. Consequently, the net effect on snow accumulation is unclear.

As the climate warms, it is likely that water supplies in many parts of Canada will decrease, thus intensifying competition and conflict over the uses to which those supplies are put. Indeed, some demands, such as irrigation, will almost certainly increase. Moreover, if rivers and lakes continue to be treated as dumping grounds for industrial effluents, any decrease in river flow will exacerbate water quality problems.

Within the Great Lakes basin, a doubled carbon dioxide climate is expected to cause a decrease of about 15% in the net water supply (The DPA Group Inc. 1988), and mean Great Lakes water levels may fall by 30–80 cm (Sanderson 1987), in spite of projected increases in precipitation. On the southern prairies, conditions could become even more severe. Even under today's climate there are years when water in the region is in short supply. In the future, dry years can be expected to occur more frequently, particularly if precipitation *variability* increases.

Recent studies indicate the difficulty of assessing the net impact of climatic change on regional hydrology. A pilot study of the Saskatchewan River basin predicted a decrease of soil moisture but could not reach a conclusion about changes in runoff or flow (Cohen *et al.* 1989). In Quebec, one study indicated that water flow in the James Bay drainage basins of La Grande, Caniapiscau, and Opinaca could increase by 7–20% (Singh 1988). However, another study, involving comparisons of several models, yielded contradictory results (Météo-Globe Canada Inc. 1989).

The impact of warming on inland fisheries, like marine fisheries, is highly uncertain. Geographical shifts of entire fish communities may occur, along with changes in the relative abundances of different species within communities (Meisner *et al.* 1987; Mandrak 1989; Regier *et al.* 1989). The result will depend ultimately on the direct effects of warmer temperatures, nutrient limitations and changes, impacts on shoreline wetlands, and changes in groundwater flow.

According to one investigation, a 2°C warming in the Great Lakes basin would increase the production of commercial fish species by an average of 26% (Meisner *et al.* 1987). However, other factors could give a different net effect. Weaker winds, for example, or warmer (and hence lighter) surface waters could decrease the mixing of nutrient-rich deep water with the surface, thus diminishing the surface nutrient supply.

A lowering of lake levels could also cause serious harm to the wetlands that currently occupy about one-third of Canada's 4 500-km Great Lakes shoreline. These areas serve as important spawning and feeding grounds for fish. If water levels were to decline rapidly, not only would they become less accessible to fish, but their structure and biological diversity would also be affected. However, a slower change in water levels could allow the wetlands and the shoreline to adjust gradually, thereby moderating the impact on fish stocks.

Groundwater is an important consideration for some fish as well. It is particularly important to heat-sensitive species such as trout because its temperature stays fairly constant year-round — about 1°C warmer than the local annual average air temperature. Its flow into the headwaters of streams maintains a cold refuge for these fish in summer. Either a warming of groundwater or a decrease in the amount of groundwater flowing into streams would reduce the extent of these refuges. On the other hand, increased groundwater flow could partly compensate for an increase in groundwater temperature.

Permafrost

Permafrost lies underneath about half the Canadian land surface, and much of it contains substantial amounts of ground ice. Because climatic warming is projected to be greatest at high latitudes, a significant thawing of permafrost can be expected. In some areas,

BOX 22.2

Prince Albert National Park

Prince Albert National Park is located in central Saskatchewan, about 65 km northwest of Prince Albert, in the boreal forest–grassland transition area. Because the boreal forest is not tolerant of either high temperatures or drought, a warmer climate with decreased soil moisture would affect this area significantly. As the climate changes, species currently near their moisture and temperature limits would show decreased vigour, although other species might be stimulated by the increased carbon dioxide concentration. Along the aspen–grassland transition zone, aspen would retreat while grasslands expanded.

If, as climate models suggest, conditions become drier in spite of increased precipitation, wildfires will likely increase too. It can be expected that species such as aspen and jack pine that are more adaptable to such disturbances will spread into the central and northern parts of the park (Wall 1989).

Such change would alter wildlife habitat and make it less suitable for certain species. Because the park is already at the southern limit for woodland caribou, these animals would likely vacate the area altogether and seek a more suitable habitat farther north. Falling lake levels might also endanger the only protected breeding colony of American White Pelicans in Canada.

Because Canada's parks have a mandate to protect endangered species and act as ecological reserves, climatic change could necessitate the creation of larger parks with boundaries that can be shifted over time.

melting of the associated ground ice will lead to unstable terrain and significant erosion problems. New wetland areas are also likely to be created. Although these will enhance habitat for some species, they will not qualitatively replace coastal wetlands lost to rising sea level or prairie wetlands lost to summer drying.

Protected areas

Canada's national parks system has been designed in part to provide protected wilderness areas in each of the major ecological regions of Canada. However, as climate changes, plants and animals will attempt to migrate. In many parks, this migration will be impeded by the hostile, human-dominated landscape surrounding them. Unless migration corridors are created, local species extinction will occur, and the Canadian parks system will be impoverished (see Box 22.2).

Wildlife and habitat

Climatic change will have the effect of shifting the location or altering the area of present wildlife habitats. Some woodland species may face local extinction if migration corridors in the form of nearly continuous forest are not available to aid their migration. In the Arctic, the reduction of sea ice cover would seriously limit the population of marine mammals and fish that are dependent on extensive ice cover and cold water. Losses of coastal wetlands to rising sea levels and the drying of prairie watering areas will reduce the area of many other important wildlife habitats as well. Habitat and wildlife losses (and the widespread thawing and erosion of permafrost) will almost certainly cause serious difficulties for the native peoples who depend on the wildlife resources of these areas.

Tourism and recreation

Climatic warming will significantly reduce and possibly eliminate the skiing industry in parts of southern Canada. With an equivalent carbon dioxide doubling, the downhill ski season in the south Georgian Bay region could be eliminated (Wall 1988), and the number of skiable days in southern Quebec could decrease by 50–70% (Lamothe and Périard 1988).

On the other hand, conditions should become more favourable for outdoor winter activities in more northerly areas, and the summer recreation season will increase in length. In Quebec, the number of days suitable for golfing could increase by 20–50% (Lamothe and Périard 1989). However, changes in water level or water quality will have a bearing on activities such as fishing, swimming, and boating, and the ecological interest and recreational potential of wetland areas may diminish.

Wilderness, wildlife, and outdoor recreation are central to Canadian tourism. Significant climatic warming could present the Canadian tourist industry with a formidable challenge of adaptation.

Transportation

Reduced winter snowfall and diminished lake and sea ice will benefit winter transportation in most parts of Canada. In the south, for example, milder winters will substantially reduce snow removal and road maintenance costs (IBI Group 1990). On the other hand, transportation over wet terrain in many northern regions is restricted to winter, when the ground is frozen. In this case, warmer and shorter winters will reduce the transportation season.

In spite of a longer ice-free season, lower water levels in the Great Lakes are expected to increase shipping costs because of the need to load ships more lightly or use vessels with shallower draft. Authorities might also be tempted to dredge waterways and harbours, but this could mobilize toxic sediments that are currently buried or undisturbed.

Energy supply and demand

Climatic warming may have some beneficial effects on energy demand. Because warming is likely to be greater in winter than in summer, the decrease in winter heating requirements should more than offset any increase in summer air-conditioning demand. However, the impact on hydroelectric supply in Canada is uncertain. Increased streamflow might occur in Labrador and northern parts of Quebec, Ontario, and Manitoba, leading to an increase in hydroelectric generating potential (Singh 1988), but capacity reductions elsewhere are a real possibility. Even where average output is unaffected, year-to-year variations could be significant and could increase the need for backup from other generating sources.

Warmer temperatures will tend to cause slight decreases in the efficiency of thermal power plants by increasing the turbine outlet temperatures. Limitations in water for cooling could also decrease efficiency and further reduce power production.

Health and comfort

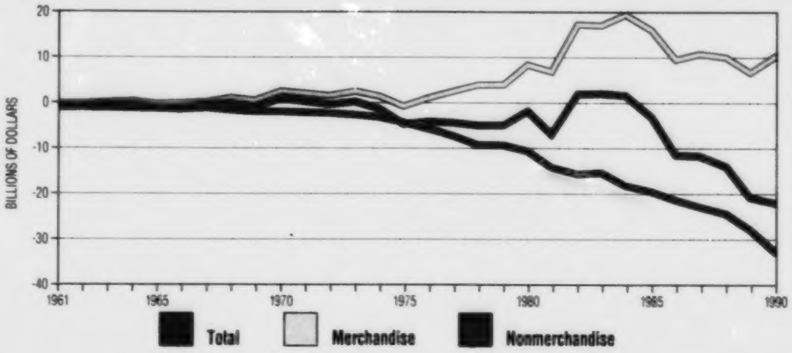
To the average person climatic warming will be most perceptible as a change in the frequency of climatic extremes. A relatively small increase in mean annual temperatures can be accompanied by a large increase in the number of days exceeding a given temperature threshold. For Canada, that would mean an increase in the frequency of summer heat waves. The elderly, who are more susceptible to heat stress than the rest of the population, would be affected most. Because people acclimatize to heat after a few days of high temperature, the effect on health is often greatest when heat waves suddenly strike urban communities that are not used to heat exposure (World Health Organization 1990).

The economy

The Canadian economy has a precarious dependence on activities that are highly vulnerable to climatic change. Figure 22.12 shows that over the last 15 years Canada's nonmerchandise balance of payments (covering such items as travel, freight, interest and dividends, and services) has steadily worsened, although it has been compensated by a growing but erratic surplus in merchandise payments. This surplus, however, comes largely from energy, agriculture, and forest products, particularly the latter, and tends to mask an expanding deficit in consumer goods, machines, and equipment (Fig. 22.13). The well-being of the Canadian economy is, therefore, coming to depend increasingly on those sectors — agriculture and forestry — that are the most climatically sensitive.

FIGURE 22.12

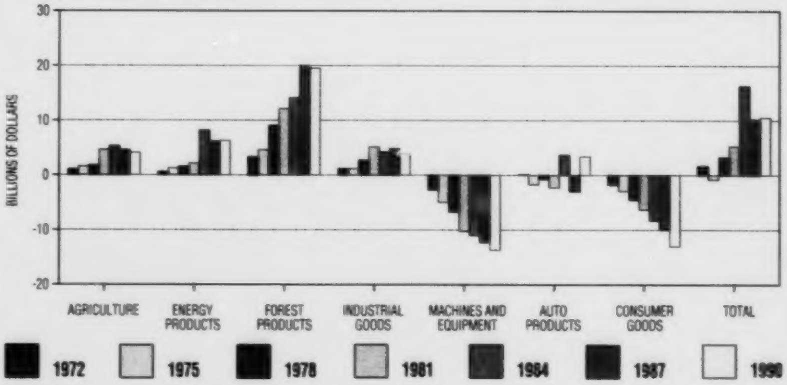
Canada's balance of international payments, merchandise and non-merchandise, 1961–90



Source: Statistics Canada (1991).

FIGURE 22.13

Canada's net merchandise exports by product group, selected years from 1972 to 1990



Source: Statistics Canada (1991).

THE NEED TO RESPOND

The consequences of climatic change associated with as little as an effective doubling of carbon dioxide are significant, particularly if climatic change occurs rapidly. It is possible that the net effect on global agriculture would be negligible and that Canadian agriculture might benefit, but there is also a risk of significant reductions in agricultural productivity even in Canada.

Impacts on Canadian forests are likely to be severe due to the rapidity of change. Water resources could be strained in many parts of the country, but impacts on marine and freshwater fisheries are unpredictable at present.

The net impact on any economic sector and region (e.g., agriculture on the prairies) depends on how precipitation would be affected by warming, and this is highly uncertain. Any increase in rainfall would have to be very substantial to offset the greater dryness of agricultural soils arising from increased evaporation. Without a sufficiently large gain in precipitation, and if the climate were to warm beyond the levels projected for an equivalent carbon dioxide doubling, there would not be enough land with suitable soils north of today's farming areas to compensate for agricultural land lost to hot, dry conditions in the south. This turn of events would have serious consequences for Canadian agriculture.

Even with aggressive and immediate global efforts to reduce greenhouse gas emissions, we are unlikely to avoid the equivalent of a carbon dioxide doubling, which present estimates suggest would occur when carbon dioxide concentrations reach about 450 ppmv. Without such a response, we can expect much larger increases. Therefore, whether we have to adapt merely to a doubling equivalent or to something much larger will depend on policy decisions taken here in Canada and in the rest of the world.

In a sense, the estimated consequences of a doubling are largely irrelevant to these decisions, for even if a doubling were beneficial there would still be a need to avoid much larger increases whose consequences would inevitably be detrimental. The rate of change must also be taken into account, because changes which, in themselves, might be beneficial to natural ecosystems could be harmful if they occurred faster than the ecosystems can adapt. If greenhouse gas emissions continue at present rates, not only will we surpass a carbon dioxide doubling equivalent but we will also increase the rapidity of climatic change.

In the final analysis, therefore, there are at least two compelling arguments for urgently reducing global emissions of greenhouse gases. One is the need to limit emissions to the equivalent of no more than a carbon dioxide doubling; the other is the need to limit the rate of climatic change.

STRATEGIES OF RESPONSE

How can people respond to climatic change? One option is to wait and adapt to warming as it occurs, a second is to undertake certain adaptive measures in anticipation of future warming, and a third is to attempt to limit the extent of the warming itself. Which should Canada choose? Undoubtedly, the country will be forced to adapt to some facets of climatic change as they happen, but it should also attempt both to limit the extent of global warming and to plan ahead to cope with the consequences of whatever warming does occur.

Anticipating future warming

Given the increases in greenhouse gases that have already occurred and the unavoidable lags in reducing emissions enough to stabilize their concentrations, some climatic warming is inevitable. This will occur within the life spans of many major projects, such as pipelines, hydroelectric developments, and coastal structures, that are now being planned. It is therefore prudent to include climatic change among the variables to be considered in the evaluation and design of these projects.

Two useful measures that can be undertaken now in anticipation of future warming are greatly increased planting of shade trees in urban areas and reforestation in rural areas. Shade trees help to cool urban areas in summer and can do much to moderate the effect of hotter and more frequent heat waves in the future. In rural areas, reforestation will help to reestablish corridors that will assist the northward migration of plants and animals in response to the shifting of climatic zones. In parts of rural southern Canada, many forest patches are now disconnected from one another. We could therefore begin at once to interconnect these isolated patches to restore the matrix of nature. Such connection building could include reforesting currently deforested river and stream banks, a measure that would also serve to moderate the effects of climatic warming on riverine environments. In agricultural areas, forest patches could be connected by windbreaks, which would also serve to reduce evaporative water losses from cropland between them.

Limitation strategies

As Table 22.6 indicates, the potential for greenhouse gas increases is so large that at some point the use of fossil fuels will have to be restricted on climatic grounds alone. If these limitations are introduced early, total climatic changes and rates of change will be smaller. Consequently, adaptation will be easier, and the likelihood or frequency of surprises will be reduced.

According to scientists at the 1988 World Conference on the Changing Atmosphere, stabilization of the atmospheric carbon dioxide concentration would require emission reductions of 50–80%. As an interim goal, the conference recommended a reduction of 20% from 1988 levels by 2005. However, developing countries, with their more fragile and less diversified economies, will be unable to avoid some short-term increases in greenhouse gas emissions.

There is universal agreement that the most effective way to limit carbon dioxide emissions is to use energy more efficiently. In Canada, certainly, there is potential for doing so (Robinson 1987). But capturing this potential requires a fundamental shift from a supply-side emphasis in energy policy to an end-use emphasis. For Canada,

this implies shifting from a resource-oriented, export economy to a more information-based, high-tech economy.

Apart from saving Canadians the huge economic costs that might eventually result from large and rapid climatic change, many of the measures needed to reduce greenhouse gas emissions are highly desirable on short-term economic grounds alone. The savings realized over the lifetime of many energy efficiency measures, such as state-of-the-art lighting and industrial motors, often surpass the cost of replacing less efficient equipment.

Furthermore, the capital requirements for improving energy efficiency are often substantially less than the capital requirements for expanding energy supply. A factory to make compact fluorescent light bulbs, for example, can be built for about $7.5 million, whereas building a power plant to produce the amount of electricity saved by the light bulbs would cost about $312 million (Gadgil and Rosenfeld 1990).[5] Similarly, a factory to manufacture low-emissivity windows can be built for $5 million and, if it were to displace offshore oil developments, could avoid capital costs of $500 million (Rosenfeld 1988).[6]

Eventually, opportunities for saving energy through improved efficiency will diminish, and increasing use will have to be made of energy sources other than fossil fuels. Nuclear energy is one option, but not the only one. Other supply options in Canada include further development of hydroelectric power, the use of biomass for electricity generation, and limited use of tidal, wind, geothermal, and solar energy. It would be counterproductive, however, to invest in new energy supply facilities before all cheaper end-use efficiency improvements had been made, because a dollar invested in new energy supply cannot be invested in more efficient energy uses (Keepin and Kats 1988).

Another strategy is to shift from high carbon-dioxide-emitting fuels such as coal and oil to natural gas, to the extent that supplies not committed for export permit. On the other hand, production and use of fuels from tar sands generally entails greater carbon dioxide production than using conventional petroleum (E.J. Wiggins, Alberta Oil Sands Technology and Research Authority, personal communication).

Some people suggest that, ultimately, the global community will have to shift from a carbon-based energy economy to a hydrogen economy. Hydrogen would be produced from water, using renewable and clean energy sources, and used in all applications currently dependent on fossil fuels. If used with the appropriate end-use technology, the only products of hydrogen combustion would be water and energy. Not only would greenhouse gas emissions be eliminated but so would all other air pollution problems associated with fossil fuels. Germany and Japan already have aggressive and well-funded research and development programs involving hydrogen end-use technologies and hydrogen production from renewable energy sources.

Responses to date

A number of governments — federal, provincial, and municipal — have already begun to respond to the challenge of climatic change. Many nations have made commitments to stabilize or reduce carbon dioxide emissions over the next few years (Table 22.8). Canada has agreed to stabilize net carbon dioxide emissions at the 1990 level by the year 2000.

TABLE 22.8

Commitments of various national governments to a reduction of their countries' contributions to world emissions of carbon dioxide and other greenhouse gases

Country	Policy plans
Australia	Stabilize CO_2, CH_4, N_2O at 1988 levels by 2000; reduce 20% by 2005
Austria	Reduce CO_2 20% from 1988 level by 2005
Belgium	Reduce CO_2 5% from 1990 level by 2000
Canada	Stabilize non-CFC gases at 1990 level by 2000
Denmark	Stabilize CO_2 at 1988 level by 2000; reduce 20% by 2005
Finland	Stabilize CO_2 at current level
France	Stabilize CO_2 at 2.0 t per capita by 2000
Germany	Reduce CO_2 25–30% from 1987 level by 2005
Iceland	Stabilize "greenhouse gases" at 1990 levels by 2000
Japan	Stabilize per capita CO_2 at 1990 level by 2000; absolute stabilization of CH_4, and, if possible, other gases, at current levels
Netherlands	Stabilize CO_2 at 1989–90 level by 1995 (if possible, 1994); reduce 3–5% by 2000
New Zealand	Reduce CO_2 20% from 1990 level by 2005
Norway	Stabilize CO_2 at 1989 level by 2000
Switzerland	No firm commitment, but expects to make 10% CO_2 reduction by 2000
United Kingdom	Stabilize CO_2 at 1990 level by 2005

Notes:

(1) U.S.A. and U.S.S.R. are among those not in favour of emission controls at present. Together, they contribute about 40% of world carbon dioxide emissions.

(2) Information is most up-to-date available in June 1991.

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[5] This assumes that the plant would produce 2 million compact fluorescent bulbs plus ballasts per year, which would displace a baseload power requirement of 208 MW. At a typical power plant capital cost of $1 500/kW, this represents a capital savings of $312 million. The savings in peak electricity requirements and corresponding capital cost savings would be somewhat larger.

[6] It is assumed that the plant would coat 2 million square metres of glass per year. For southern Ontario climatic conditions, the windows would save the equivalent of 10 000 barrels of oil per day. For colder climates, the savings would be greater.

Within Canada, the City of Toronto has committed itself to meeting the recommendation of the 1988 Conference on the Changing Atmosphere: a 20% reduction of emissions from the 1988 level by the year 2005. The city's environmental advisory committee recently released a comprehensive set of strategies for achieving that target and laying the foundation for the larger emission reductions that must follow (Special Advisory Committee on the Environment 1991). The City of Vancouver is also closely studying a comprehensive set of actions to substantially reduce its carbon dioxide emissions. Other municipal, provincial, and federal committees are currently studying the problem.

Within the private sector, the chemical industry is playing a key role in phasing out the use of CFCs — an action that, besides protecting the ozone layer, will eliminate a class of greenhouse gases that otherwise could have become more important than carbon dioxide. In the metal-processing industries, a number of measures are under way to reduce emissions that cause acidic deposition. Some of these involve the replacement of old production facilities with more efficient advanced technology that substantially reduces the use of fossil fuel energy. In a similar vein, the Canada Centre for Mineral and Energy Technology (CANMET) and the Canadian Electrical Association (CEA) recently announced a five-year research program to develop furnace and boiler processes that would reduce emissions of greenhouse gases and acid-forming pollutants.

Progress is also being made in developing ways to reduce emissions in the residential sector. A demonstration home recently completed north of Toronto, for example, is projected to consume only about 40% of the total energy used by a comparable R-2000 home. Until recently, R-2000 homes represented the most energy-efficient house design available, requiring only about two-thirds of the energy needed for a comparable conventional house.

Canada's role

Resolving the problem of greenhouse gas emissions will require global cooperation. As a wealthy, technically advanced country having one of the highest per capita carbon dioxide emissions in the world, Canada has a special responsibility to lead by example. Reducing Canada's greenhouse gas emissions will require creative and innovative thinking. But technical innovation alone will not be enough. Political, institutional, and economic innovations will be needed as well.

There is growing evidence that the biosphere at northern latitudes is serving as a significant sink for a portion of the carbon dioxide that humans are adding to the atmosphere (Tans *et al.* 1990). With rapid climatic change, however, Canada's forests could change from a possible net sink to a net source of carbon dioxide. That prospect places a special responsibility upon Canadians to safeguard the health of the vast tracts of woodland that cover this country.

The challenge of global warming will require unprecedented global cooperation. Because the impacts on Canada will depend largely on what happens elsewhere, it is vital that this country set the right example. At the same time, the technical challenge of reducing greenhouse gas emissions is a tremendous opportunity, an opportunity which, if seized, can restore to Canadians both a healthy environment and a healthy economy.

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23

COURTESY OF INDUSTRY, SCIENCE AND TECHNOLOGY CANADA, OTTAWA

HIGHLIGHTS

As a result of the discovery of the depletion of ozone in the stratosphere, environmental problems have been recognized as global and potentially catastrophic in nature.

◆

The existence of the antarctic ozone hole has been confirmed and attributed in large measure to chlorofluorocarbons, chemicals used in refrigerators, spray cans, fire extinguishers, and industrial processes.

◆

There is strong evidence for the existence of a similar hole each spring over the Arctic, as well as evidence for a decline in global stratospheric ozone levels.

◆

Although there has been no positive evidence yet of an increase in the ultraviolet radiation (UV-B) that reaches the Earth's surface, the ozone-depleting substances that have already been released to the atmosphere will result in an unknown degree of stratospheric ozone depletion and associated health and environmental consequences.

◆

The signing of the Montreal Protocol on Substances that Deplete the Ozone Layer in 1987 was a very important step towards effective protection of the stratospheric ozone layer.

◆

Further progress has been made in a June 1990 amendment to the Montreal Protocol, which called for an end to the production and importation of most ozone-depleting chemicals by the year 2000. Canada has committed itself to achieving that target by 1997.

◆

The challenge Canada now faces is to complete phase 1 of the Montreal Protocol and, in the face of a turbulent international economic and political situation, move on successfully to subsequent actions.

◆

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INTRODUCTION

Ozone is one of the least conspicuous, yet one of the most crucial, constituents of the atmosphere. Although it makes up less than 1 ppm of the atmosphere's total volume, life on Earth would be impossible without it. Because ozone absorbs ultraviolet radiation from the sun, it partially screens living things on the Earth's surface from the destructive effects of these rays. By reemitting the absorbed energy as heat, it also helps to shape the atmosphere's thermal structure and influence its circulation, thus affecting global weather and climate patterns.

Although ozone occurs in small amounts in the lower atmosphere, where it is a pollutant, most of the world's ozone is found in the stratosphere, some 15–50 km above the Earth's surface. The greatest concentration of ozone — never more than about 10 ppm by volume (ppmv) — occurs at an altitude of about 25–35 km, where it forms what is commonly known as the ozone layer. Clearly, any interference with the ozone layer could have hazardous consequences for life on Earth.

In recent years the stratospheric ozone layer has diminished and the evidence that this is caused by industrial pollution is now convincing. This chapter describes the observed changes, reviews what is known about the process of ozone depletion and examines the potential human and environmental effects of increased ultraviolet radiation. Possible solutions to the problem are discussed.

> “The possibility that the stratospheric ozone layer could be depleted by half at certain latitudes and seasons would have been deemed a preposterous and alarmist suggestion in the early 1980s.”
>
> — Solomon (1990)

STRATOSPHERIC OZONE FORMATION AND DISTRIBUTION

Ozone is produced when high-energy ultraviolet radiation from the sun strikes an oxygen molecule and breaks it into two highly reactive oxygen atoms (Fig. 23.1). These atoms then combine rapidly with intact oxygen molecules to form ozone.

FIGURE 23.1

Natural formation and breakdown of ozone in the stratosphere

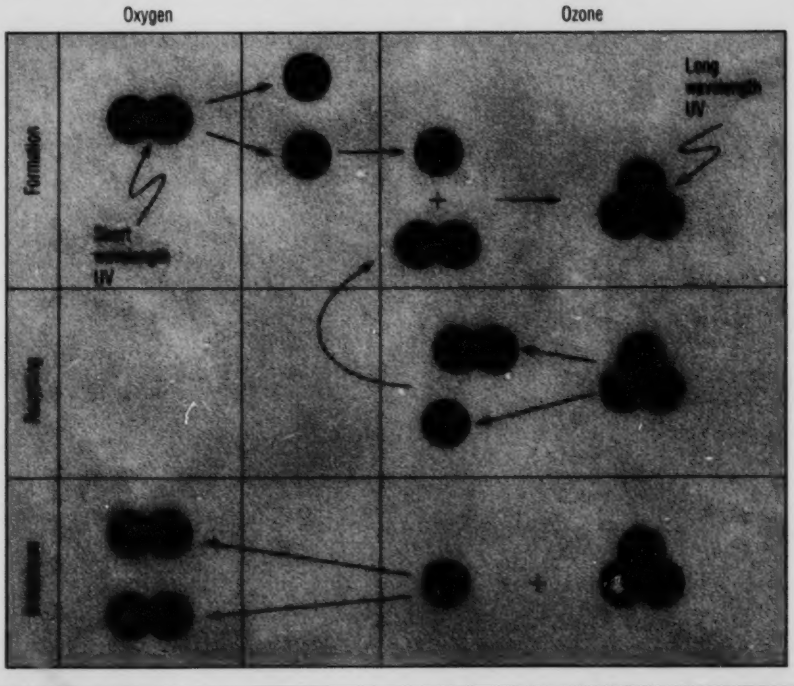
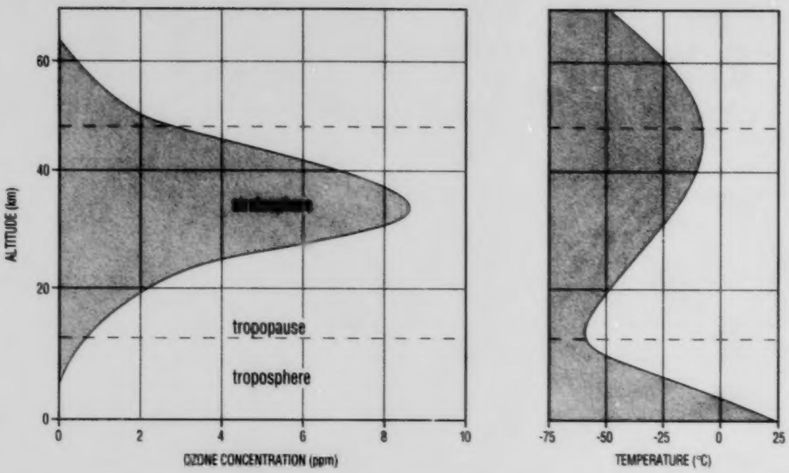


FIGURE 23.2

Vertical structure of the atmosphere and vertical distribution of ozone



Source: United Nations Environment Programme (1987).

Ozone can be broken down or dissociated by sunlight (Chapman 1930), a process known as photolysis. It can also be broken down through reaction with various chemicals in the atmosphere, most notably those oxides of hydrogen known as hydroxyl and hydroperoxyl radicals. Oxides of nitrogen also play a critical role in ozone destruction (Crutzen 1970); they are particularly significant because their abundance in the atmosphere is affected by human as well as natural factors.

Formation and destruction of ozone proceed simultaneously. In a normal, unperturbed atmosphere, these processes balance each other, and ozone concentrations stay within reasonably well-defined limits.

The distribution of ozone is closely linked to the vertical structure of the atmosphere (Fig. 23.2). The lowest layer, the troposphere, is the moist, turbulent region where weather and climatic processes take place. It extends roughly 10–15 km above the Earth's surface and is characterized by a decrease in temperature with altitude. Above the troposphere is the stratosphere, extending upwards to an altitude of about 50 km. It is characterized by relatively dry and stable air and an increase in temperature with altitude.

The boundary between the two layers is known as the tropopause, and mixing across it occurs slowly. Substances normally take a long time to pass from one layer to the other, except in the case of violent phenomena such as extremely severe storms, volcanic eruptions, and large above-ground nuclear explosions, which may inject material directly through the tropopause into the stratosphere.

Ozone formation takes place primarily in the stratosphere, where intense, unattenuated ultraviolet radiation first interacts with significant amounts of molecular oxygen. Because the tropopause impedes its downward passage into the troposphere, most of the globe's ozone — about 80% of it — remains in the stratosphere. The tropopause also acts as a barrier to the ascent of ozone-destroying chemicals from the lower atmosphere. Consequently, most of these chemicals are broken down by chemical and physical processes in the troposphere before they have time to reach the stratosphere in significant quantities.

The total quantity of ozone above a certain point on the Earth's surface is known as the total column ozone amount. It is customarily measured in Dobson units (DU), with 100 DU being equal to an imaginary layer of pure ozone gas, 1 mm thick, at standard sea level temperature and pressure. Globally, the average ozone concentration is 350 DU, or the equivalent of 3.5 mm of pure gas compressed to surface pressure and temperature.

As a consequence of stratospheric circulation patterns, ozone is not distributed evenly around the globe (Fig. 23.3). In the upper stratosphere, solar radiation causes ozone to break down at about the same rate as it forms. In the lower stratosphere, below 25 km, ozone is more stable and lives long enough to be transported both horizontally and vertically over long distances by stratospheric winds. Because these winds transport ozone from the equator towards the poles, natural ozone concentrations, which attain more extreme values than the averages shown in Figure 23.3, vary latitudinally from about 250 DU over the tropics to approximately 450 DU over subpolar regions. These stratospheric wind patterns cause particularly large amounts of ozone to accumulate in polar regions during the winter, giving rise to ozone concentrations as high as 600 DU in the polar spring.

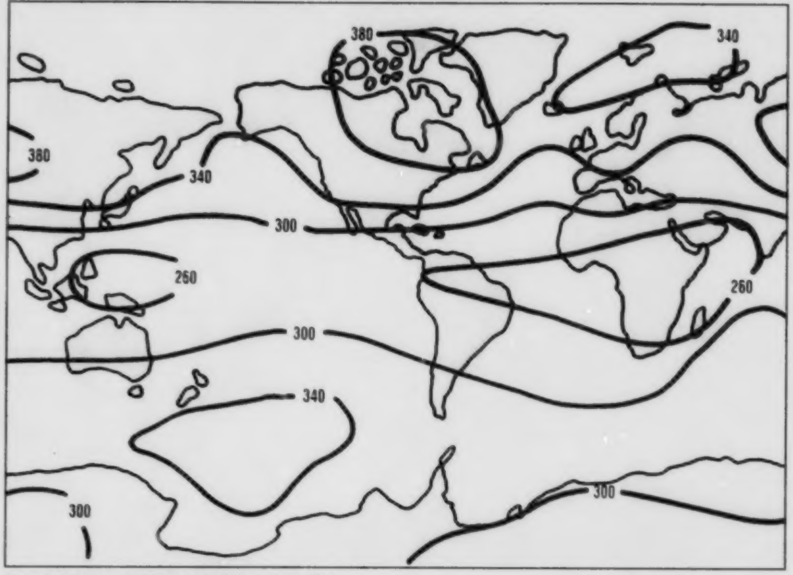
As well as varying spatially, ozone amounts vary with time, changing daily and seasonally and fluctuating with a number of other natural phenomena whose cycles are measured in years. All these influences need to be taken into account if we are to determine accurately whether ozone amounts are increasing or decreasing and if we are to separate the artificial, human impact on the atmosphere from natural effects.

CONCERN OVER THE INTEGRITY OF THE OZONE LAYER

The possibility of a human threat to the ozone layer was first raised in the early

[illegible]

Average global distribution of natural ozone



Note: Ozone concentrations are in Dobson units (DU).
Source: London and Angell (1982).

1960s, when it was argued that water vapour from aircraft and rockets flying in the stratosphere might initiate ozone depletion (Hampson 1964, 1974). This concern became more focused in the early 1970s, with increasing penetration of the stratosphere by supersonic military aircraft and missiles and with the expectation that large fleets of supersonic transport aircraft, cruising at stratospheric altitudes, would eventually come into service with the world's airlines. It was also proposed that nitrogen oxides from the exhausts of these aircraft could be detrimental to ozone. Although the large fleets of supersonic transport aircraft did not materialize, concern over emissions of nitrogen oxides from fossil fuel combustion and agricultural fertilizers kept stratospheric ozone on the scientific and public agendas (Crutzen 1970; Johnston 1971).

The development of the National Aeronautics and Space Administration's (NASA) first space shuttle raised an additional threat: the possibility that chlorine, a trace component of the shuttle's exhaust gases, could facilitate the depletion of the ozone layer. It was soon determined that this threat was not significant, but interest in the ozone-depleting potential of chlorine revived shortly afterwards with the discovery of chlorofluorocarbons (CFCs) in the atmosphere.

CFCs are stable, nontoxic, synthetic chemicals with a wide variety of applications — as refrigerants, aerosol propellants, industrial solvents, cleaning fluids, blowing agents for the manufacture of foams, and agents in many other manufacturing processes. Although it was not immediately apparent that CFCs posed an environmental threat, a number of scientists became interested in the fate of these chemicals in the atmosphere. Interest turned to concern when Molina and Rowland (1974) argued that, because CFCs are chemically stable, they would persist in the atmosphere long enough to diffuse upwards into the stratosphere. Once there, they would be exposed to intense solar radiation and would break down to liberate reactive chlorine atoms, which would cause the dissociation of ozone.

Further chemical studies, particularly by Stolarski and Cicerone (1974), extended and clarified the scheme of reactions by which CFCs contributed to the breakdown of ozone. For some time, however, there was no direct evidence that such reactions actually occurred in the atmosphere. It was a novel idea, and there was understandable resistance to it, especially from the producers and users of CFCs.

Controversy over CFCs and other potential threats to the ozone layer continued throughout the late 1970s and into the 1980s. Laboratory and field studies and the increasing use of computer simulation techniques that modelled the chemical and dynamic behaviour of the atmosphere provided further support for the idea that chlorine from CFCs was damaging the ozone layer. Environment Canada's Project Stratoprobe, for example, explored the upper atmosphere over Saskatchewan, confirming the breakdown of CFCs in the stratosphere and revealing the presence of chlorine monoxide, an important indicator of the occurrence of ozone-depleting reactions. Another study suggested that bromine (like chlorine, a member of the halogen family) was also a potent threat to ozone (Wofsy *et al.* 1975). This suggestion raised concerns about the emission of halons — compounds containing bromine that are widely used as fire-extinguishing agents and are similar in many ways to CFCs.

Then came the dramatic announcement in 1985 that springtime ozone values in Antarctica had declined by up to 50% since the late 1970s (Farman *et al.* 1985) — a phenomenon that has popularly but inaccurately come to be called the antarctic ozone hole. This report was initially met with skepticism but was soon confirmed by other researchers using ground-based instruments (Chubachi 1985) and satellite sensors. In addition, a review of old sets of data showed that they had been misinterpreted, and their reappraisal also confirmed the new findings.

Up to this point, scientists had not realized that a major ozone loss had already occurred. Although losses were anticipated, they were not expected to be so severe, nor were they expected to take place in the lower stratosphere over Antarctica. In fact, the best projections at the time suggested that the ozone column could be depleted by about 5%, with the largest change occurring at a height of 40 km in the mid-latitudes, probably sometime in the next century (Solomon 1990). The antarctic depletions, therefore, were a complete surprise.

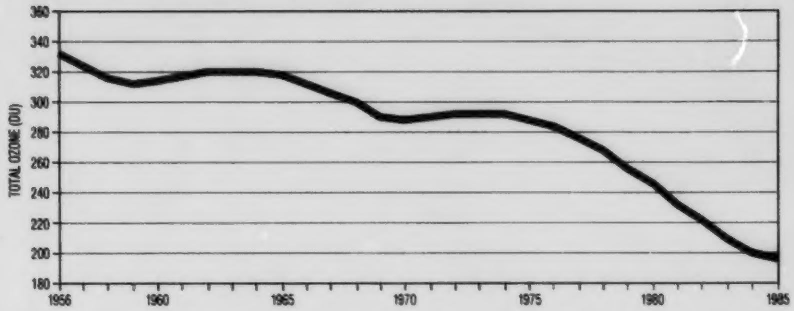
The antarctic ozone hole is a seasonal phenomenon, beginning in September, early in the southern spring, and lasting about two months. In the early 1960s, spring ozone values over Antarctica had averaged 320 DU, but the average had dropped to 200 DU in 1984 (Fig. 23.4). At its worst, up to 50% of the total column ozone was lost over the central part of the continent for several months, with minimum values dropping as low as 130 DU. Most of the ozone between 12 and 24 km above the Earth's surface had gone. As the ozone-depleted air spread northwards at the beginning of the summer, the depletion extended into the mid-latitudes to cover parts of South America, South Africa, and Australasia.

In 1987, 15% of the southern hemisphere (an area twice the size of Canada) was affected (Atkinson *et al.* 1989; Solomon 1990), and ozone measurements fell to a record 121 DU. The 1988 depletion was less severe. However, in September–October 1989, the loss was almost as great as in 1987. Minimum values of 121 DU were reported, and the "hole" covered approximately 26 million square kilometres (Fig. 23.5).

The discovery of the antarctic depletions sparked an intensification of research, as scientists attempted to determine whether it was a natural phenomenon or whether it was somehow related to the emission of CFCs to the atmosphere. Further studies revealed a possibly similar, although smaller-scale, phenomenon in the Arctic. In addition, a small loss of ozone

[illegible]

Total ozone values over Antarctica, 1956–85

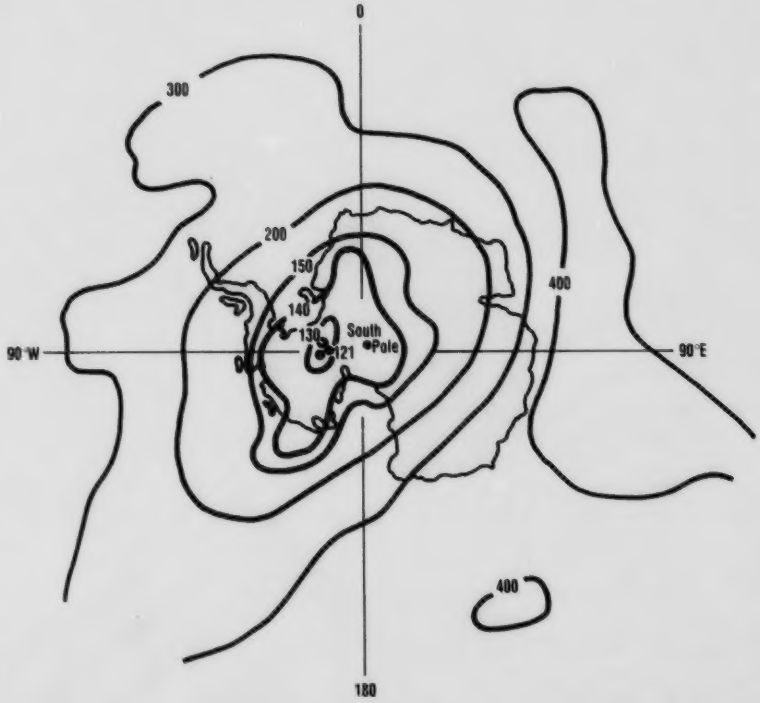


Note: Measurements of total ozone amounts over Halley Bay in the Antarctic during the southern spring have shown a 40% decline between 1956 and 1985. The curve represents the smoothed average of the annual measurements.

Source: United Nations Environment Programme (1987).

FIGURE 23.5

Total ozone abundance over the southern polar region, October 10, 1989

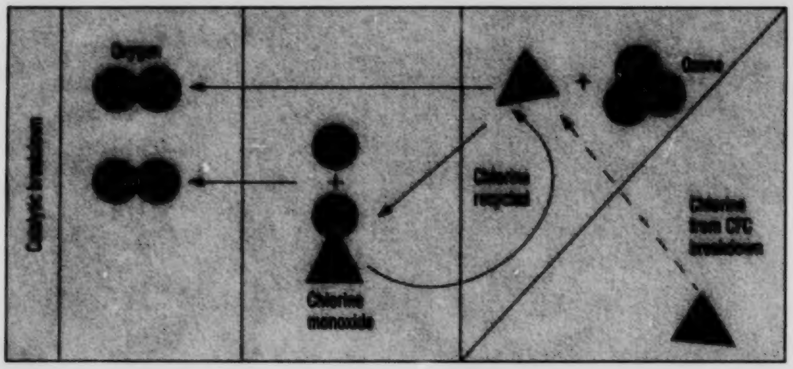


Note: Ozone concentrations are in Dobson units (DU).

Source: Environment Canada, Atmospheric Environment Service.

FIGURE 23.6

Destruction of ozone by catalysts



appears to have taken place over most of the northern hemisphere. This effect cannot readily be attributed to any known natural processes (Evans 1987; Hofman *et al.* 1989; Plumb 1990; Proffitt *et al.* 1990; Schoeberl and Hartmann 1990).

OZONE DEPLETION: CAUSES, PATTERNS, AND TRENDS

The pattern of ozone depletion around the world is marked by two distinct phenomena: the very large loss of ozone over the Antarctic, perhaps as much as 60%, as the sun returns to the region in the spring (and similar but much less dramatic losses in the Arctic); and a small general decline in global ozone of less than 0.3% per year over the past decade.

It is now clear that the ultimate cause of both these phenomena is a chemical process resulting from the emission of long-lived chlorine and bromine compounds into the atmosphere. However, natural atmospheric processes also play a key role in the complex chain of events that finally culminates in the destruction of stratospheric ozone. Moreover, both the chemical and the atmospheric processes involved in polar ozone depletion differ markedly from those affecting ozone levels in the rest of the world.

The chemistry of ozone depletion

Recent research has concentrated on improving our understanding of the chemical reactions involved in ozone depletion and identifying the sources of the substances and the motions of the atmosphere that allow the reactions to take place (McElroy and Salawitch 1989). In particular, attention has focused on the role of catalysts in these reactions. Catalysts are substances that potentiate or accelerate chemical reactions without themselves being changed in the process. Because of this, they are recycled and are able to participate in the reaction many times, so that a small quantity of catalyst can facilitate the change of a much greater quantity of the other reactants (Fig. 23.6).

In a normal, unpolluted atmosphere, the breakdown of ozone is catalyzed chiefly by oxides of nitrogen and hydrogen, but pollutants of human origin now provide a much more effective source of ozone-depleting catalysts. The most important of these anthropogenic catalysts are the elements chlorine and bromine, which exist in the upper atmosphere in a number of active physical and chemical forms called ions and free radicals. Several other chemicals may also take part in ozone destruction. In all, about 40 different substances, participating in several hundred chemical reactions, affect the abundance of ozone. Most of these reactions are directly or indirectly affected by the availability of the reactive oxygen atoms.

Most attention focuses on chlorine because of its large abundance. Molecule for molecule, however, bromine is a more potent destroyer of ozone, because it is less likely than chlorine to form stable compounds, and therefore more of it remains in the chemically active form. Because each halogen atom can cause the dissociation of approximately 100 000 ozone molecules, it is clear that even trace quantities of these substances in the stratosphere have the potential for doing considerable harm, especially when one considers how little ozone there is in the atmosphere, even at its normal abundance.

Many organic compounds containing chlorine and bromine are liberated into the atmosphere by both natural and nonnatural processes. Most contain hydrogen atoms, and the relatively fragile bond between carbon and hydrogen behaves as a weak link in the molecule. Because this bond is readily broken by sunlight and a number of chemical agents present in the lower atmosphere, these compounds do not survive long enough to reach the stratosphere.

The most important ozone-depleting substances — CFCs, halons, and carbon tetrachloride — do not contain hydrogen and therefore are sufficiently stable to survive intact in the atmosphere for many years. Their long atmospheric lifetimes (ranging from 20 to 120 years) enable them to eventually reach well into the stratosphere, where the intense ultraviolet radiation causes their breakdown and effects the release of chlorine and bromine ions. An exception is methyl chloroform, which, although it contains hydrogen, is produced and emitted in such large quantities that it constitutes a threat to ozone despite its relatively short atmospheric lifetime.

Chlorine and bromine emitted from human activities have been confirmed as the main cause of the loss of stratospheric ozone (Ozone Trends Panel 1988; McElroy and Salawitch 1989; World Meteorological Organization/United Nations Environment Programme 1989; Solomon 1990). Moreover, the atmospheric concentrations of these gases have approximately doubled since the mid-1970s. For example, natural background levels of chlorine, such as existed in the unpolluted atmosphere of a century ago, are thought to have been in the order of 0.6 ppb by volume (ppbv). Present levels are now 3.5 ppbv, almost six times greater, and they are increasing by about 1 ppbv each decade.

Depletion of ozone over the Antarctic

Discovery of the antarctic ozone depletion ignited a major controversy that revolved around both the nature and the cause of the phenomenon. Was the primary mechanism chemical or dynamical (i.e., related to the large-scale movements of the antarctic air mass)? Was it a natural phenomenon, or was it driven by some human influence on the atmosphere?

Initially, there was some resistance to a purely chemical explanation of the event. As no direct measurements of chlorine and CFC abundance were then available from the Antarctic, this was understandable. In addition, what was known of the relevant atmospheric chemistry indicated that most of the chlorine would be locked up as inactive chlorine nitrate and hydrogen chloride and unable to participate in ozone-destroying reactions.

Some researchers sought an explanation in the sunspot cycle and suggested that variations in solar activity might be creating larger-than-average levels of nitrogen oxides, which are known to be potent destroyers of ozone. Another suggestion focused on the circumpolar vortex — a circular motion of air that develops in the stratosphere around the poles. The vortex forms in winter and, when well developed, partially isolates the air mass inside it from the rest of the atmosphere. According to this hypothesis, ozone inside the vortex might be diluted by ozone-poor air rising from below, creating an apparent "hole" regionally but without any net loss on either a hemispheric or a global scale.

As research continued, it became clear that, although the vortex was an important factor in the depletion of ozone, unsuspected chemical processes were also taking place. The large, rapid depletions appeared to be related to the occurrence of polar stratospheric clouds (PSCs), which form in the vortex during the sunless polar winters when temperatures in the lower stratosphere fall below –80°C. The severe depletions of 1987 and 1989, for example, were associated with temperatures between –85°C and –90°C within the vortex. In 1988, however, when the depletion was not as severe, the vortex was less well developed and temperatures were between –78°C and –80°C.

Depending on meteorological conditions in the stratosphere, at least three different types of PSCs may form (McElroy and Salawitch 1989; Anderson *et al.* 1990), and the reactions that occur and the rate at which they take place are different in each of them. Although the chemistry is very complex and, as yet, poorly understood, the general processes can be outlined fairly simply.

PSCs are partly composed of nitric acid, whose formation locks up much of the potentially available nitrogen in the lower stratosphere. When sunlight returns in the polar spring, chlorine and bromine nitrates in the PSCs react with hydrogen chloride and break down rapidly on the surface of the ice crystals of the clouds, releasing active chlorine and bromine. Because the air within the PSCs is so heavily denitrified, very little of the chlorine and bromine can return to the harmless nitrate form. Consequently, these substances remain free to participate in a number of ozone-depleting reactions, generating chlorine monoxide and bromine monoxide in the process (Schoeberl and Hartmann 1990). In this way, the PSCs and conditions in the antarctic stratosphere "set the stage for remarkable enhancements in the abundances of ozone-damaging forms of atmospheric chlorine at the expense of relatively benign forms" (Solomon 1990).

As a result of these processes, stratospheric concentrations of chlorine monoxide in the Antarctic may reach 1 ppbv or more, which is 100 times the concentration expected for the normal stratosphere. Indeed, the high concentrations of chlorine monoxide are a clear indicator that severe chemical depletion of the ozone is occurring. Figure 23.7 shows how the proportions of these gases within the circumpolar vortex changed as the antarctic ozone depletion of 1987 developed.

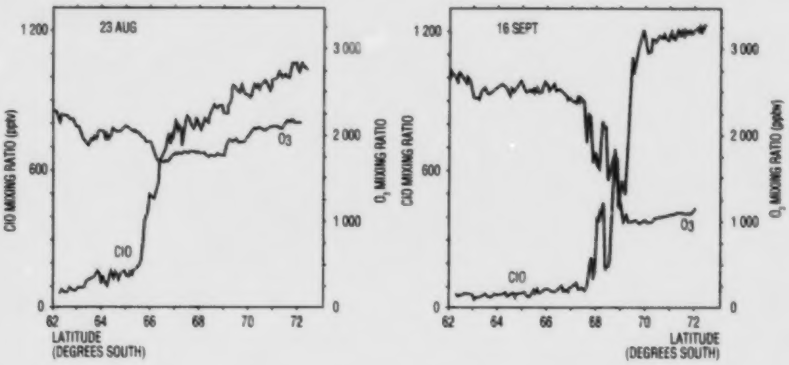
As the relationship between meteorological and chemical processes became clearer, scientists anticipated that years of severe and less severe ozone depletion would alternate. This is because the stratospheric wind patterns that affect the strength and persistence of the vortex, and therefore the ozone-depleting reactions inside it, vary with a natural cycle of approximately two years. Following the large loss of ozone in 1989 (when the minimum level reached 121 DU), the 1990 minimum of 125 DU was therefore totally unexpected, especially as the meteorological processes were, as predicted, conducive to a small ozone hole (Kerr 1990).

It is now clear that the loss of stratospheric ozone is affected by an even more complex array of meteorological phenomena (Schoeberl and Hartmann 1990). Although the ozone hole is affected by natural processes and even dependent upon them as predisposing factors, it is primarily a result of the human, chemical insult to the stratosphere. As Anderson *et al.* (1990) concluded, after reviewing the current status of the scientific evidence, antarctic ozone depletion "would not have occurred had CFCs not been synthesized and then added to the atmosphere."

FIGURE 23.3

Comparison of chlorine monoxide (ClO) and ozone (O_3) levels over Antarctica during development of the 1987 ozone depletion

The diagrams show chlorine monoxide and ozone ratios as measured from an aircraft flying through the circumpolar vortex over Antarctica on August 23 and September 16, 1987. The chlorine monoxide levels rose sharply as the aircraft entered the vortex. A significant drop in ozone abundance is evident after three weeks of exposure to elevated levels of chlorine monoxide.



pptv = parts per trillion by volume

ppbv = parts per billion by volume

Source: Anderson *et al.* (1990), reprinted with permission from *Science*.

An arctic ozone hole?

The discovery of the seasonally recurring antarctic depletions inevitably led to a search for a similar event in the northern hemisphere. Results were not long in coming. In 1986, Environment Canada researchers, using instrumented balloons flown from Alert, N.W.T., and other northern locations, found evidence of a depletion of arctic ozone (Evans *et al.* 1987; Hofman *et al.* 1989; Evans 1990). The occurrence of such abnormal processes in the arctic stratosphere has been confirmed by data from satellite instruments and through direct measurements taken from aircraft (e.g., Brune *et al.* 1988; Turco *et al.* 1990).

Like the antarctic depletions, the arctic event is also a springtime phenomenon, but it is much less extensive and much less severe than its southern counterpart, with total ozone column losses in the 4–10% range. Given that the arctic stratosphere is affected by the same pollutants and general conditions as the southern hemisphere and is "chemically primed for ozone depletion" (Proffitt *et al.* 1990), why should the arctic depletions be less dramatic? Essentially, the reason is meteorological. The arctic stratosphere is warmer, and the circumpolar vortex is weaker and less persistent (usually breaking up before the arrival of the springtime sunlight). Consequently, the special conditions that lead to major depletions do not occur as readily or as consistently from year to year as in the Antarctic.

It is not yet clear, however, whether a net loss of ozone has occurred in the region. A recent study suggests that a major local loss of up to 50% of the arctic ozone between 17 and 20 km above the Earth's surface occurred in the winter of 1989. This event was associated with very high levels of chlorine monoxide, the principal indicator of severe ozone loss (Proffitt *et al.* 1990). Proffitt *et al.* (1990) argued that this massive depletion did not appear as a "hole" because the ozone was continually replenished by ozone-rich air from outside, thus masking the true loss. These findings rely on assumptions about the meteorology of the Arctic that cannot yet be confirmed (Plumb 1990; Proffitt *et al.* 1990), but the conclusions certainly cannot be discounted (e.g., Schoeberl and Hartmann 1990).

There is also new evidence for a long-term trend in the decline of winter ozone in the mid-latitudes of the northern hemisphere. In addition, the Montreal Protocol Scientific Assessment Panel has recently concluded that ozone depletion in mid-latitudes is likely to double over the next decade; and that the ozone depression that occurs in the spring appears to be extending into the summer months. (personal communication, Atmospheric Environment Service). Canada, of course, also has a major interest in the arctic environment and is intensifying its research efforts. We are now participating with other circumpolar nations in a joint program of stratospheric research and monitoring, and the federal Green Plan (Government of Canada 1990) has made provision for establishing an arctic observatory for this purpose.

Global ozone trends

The large and very obvious ozone losses in the Antarctic obscure the fact that the detection of relatively small changes in global ozone amounts or in mid-latitude trends over long periods is technically difficult with currently available instruments. Natural background levels of ozone vary widely in both space and time. In addition to the natural variation with latitude and season, one must also take into account the 11-year sunspot cycle, the alteration in the pattern of stratospheric winds every two years or so, and the sporadic El Niño Southern Oscillation,[1] about

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[1] The El Niño Southern Oscillation (ENSO) is a climatic event named after a warm current that arises off the South American coast. Possibly caused by slight changes in atmospheric circulation, El Niño is linked to reversals in weather patterns and extreme weather events such as hurricanes.

Table 23.1

Canadian trends in total ozone, 1965–86

		% change between 1965–75 and 1976–86		
Location	**Latitude (°N)**	**Summer**	**Winter**	**Total**
Resolute, N.W.T.	74.7	–0.8	–1.4	–1.6
Churchill, Man.	58.8	–1.4	–4.2	–2.5
Edmonton, Alta.	53.6	+0.8	–4.7	–1.8
Goose Bay, Nfld.	53.3	–0.1	–2.4	–0.8
Toronto, Ont.	43.8	–1.3	–1.3	–1.2

Source: Environment Canada, Atmospheric Environment Service.

every three to five years. Episodic events such as the eruption of the Mexican volcano, El Chichon, may also affect the abundance and distribution of ozone through the injection of ozone-depleting chemicals into the stratosphere. There are other atmospheric changes going on too — some natural and some induced by human activity — that affect ozone abundance. Greenhouse warming is an obvious example, but rising levels of nitrous oxide (0.3% yearly) and methane (1% yearly) can also be expected to directly influence the levels of ozone (World Meteorological Organization 1985).

Scientists began systematic measurements of the total amount of ozone and, at some locations, its vertical distribution in the 1930s and 1940s. At the time, they were primarily interested in the ozone layer's influence on the general circulation of the atmosphere. A worldwide measurement program was started during the International Geophysical Year in 1957, with the World Meteorological Organization (WMO) standardizing and coordinating data.

Canada has been involved in these activities from the outset, and Canadian scientists have made major contributions to the development of instruments and methods used in ozone research. Today's most advanced ozone spectrometer, the automated Brewer spectrophotometer, is a Canadian instrument. Since 1960, Canada has operated the World Ozone Data Centre on behalf of the WMO. The centre collects all of the data from the Global Ozone Observing System (GO$_3$OS) and publishes them in a bimonthly bulletin, *Ozone data for the world*.

The careful measurements made by scientists around the world have helped us understand the characteristics of the normal ozone layer and the extent to which it has been depleted by chemicals from human sources. Nevertheless, the global monitoring network still suffers from considerable technical and operational limitations. It gives barely adequate coverage of the globe and is biased towards the northern hemisphere. Also, it is equipped mainly with ground-based Dobson instruments, whose sensitivity is not adequate for measuring very small, long-term trends. Their operation requires great expertise if valid data are to be obtained from all stations of the network, and this standard is not always achieved in practice. Moreover, the instrument looks upwards and measures the total amount of ozone overhead, including tropospheric as well as stratospheric ozone. This is a serious deficiency, as there is reason to believe that an increase in tropospheric ozone may have masked a decline in stratospheric ozone in recent years. Although a technique can be used with the Dobson instrument to separate tropospheric from stratospheric variations and determine ozone changes with height, it is limited in its application.

The Brewer spectrophotometer promises to remedy some of these problems. Although 60 of these instruments are now installed in 46 locations in 20 countries, they are not yet fully deployed throughout the network. Because most of the early GO$_3$OS records were taken with Dobson instruments, it is desirable to have complete and long-term comparisons with the Brewer data before replacing the Dobson instruments for trend assessment.

Satellite-mounted instruments, which look down upon the stratosphere rather than up through the total ozone column, should have provided a major opportunity to check the validity of the surface network's results. Unfortunately, the most important of these instruments has undergone a change in sensitivity that has introduced a bias into the data. This has not been a great problem in assessing the large losses of ozone in the Antarctic, but it is a serious limitation when looking for changes that average less than 1% yearly. The Brewer instrument is scheduled for deployment on a future mission of the U.S. space shuttle and should help to provide accurate measurements of stratospheric ozone as well as a cross-check on the performance of other instruments. Aircraft-, balloon-, and rocket-mounted instruments also enable direct ozone measurements to be made, but, because of cost and logistic considerations, they are not feasible for use in regular monitoring programs.

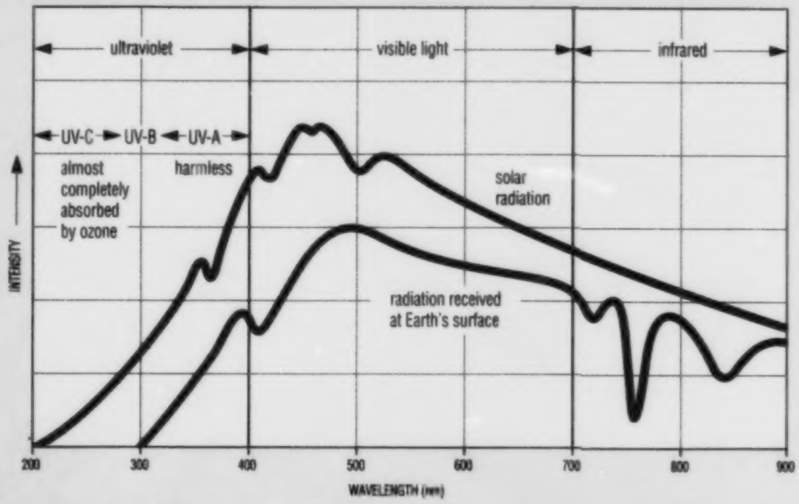
The most recent estimates of ozone depletion, based on satellite data analyzed by NASA, suggest that losses are occurring in the mid-latitudes of the northern hemisphere at a rate of 4–5% every 10 years. Loss rates are highest during the winter months and remain high into April and May. Globally, the depletion rate is estimated at 2–3% each decade. These rates are approximately double those of the best earlier estimates, which were based on incomplete data.

Evidence, from the global network, of an ozone decline in the northern hemisphere is reflected in data from the Canadian stations (Table 23.1). A

FIGURE 23.8

Solar radiation received at the Earth's surface, by wavelength

Most of the solar radiation reaching the Earth's surface is in the infrared, visible light, and ultraviolet portions of the electromagnetic spectrum. Almost none of the highly destructive UV-C radiation reaches the Earth's surface, but a portion of the less dangerous but still potent UV-B radiation does. A nanometre (nm) is a millionth of a millimetre.



Source: United Nations Environment Programme (1987).

comparison of results for two decades, 1965–75 and 1976–86, suggests a decline in total ozone of 0.8–2.5% per decade, with substantial losses occurring in the winter at middle and high latitudes. Total ozone over Toronto declined by approximately 4% between 1975 and 1987 (Evans *et al.* 1987) and by 6–8% over the past 25 years.

BIOLOGICAL EFFECTS

Concern over a possible depletion of the ozone layer derives much of its strength from fear of the damaging biological effects of ultraviolet radiation. However, not all of the ultraviolet spectrum is equally harmful (Fig. 23.8). Most of the longer-wavelength ultraviolet radiation (320–400 nm) — known as UV-A — reaches the Earth's surface but, because it is of relatively low energy, does little harm to living organisms within its normal range of intensities. The shortwave, high-energy UV-C (200–280 nm), in contrast, is potentially very destructive but is almost completely absorbed by the atmosphere and does not reach the surface in appreciable quantities. It is the middle portion of the spectrum, known as UV-B (280–320 nm), that is of most concern, as much of it penetrates the atmosphere to ground level and has sufficient energy to cause a wide variety of damage to living organisms (Urbach 1969) if they are excessively exposed. The amount of UV-B that is transmitted downwards at a given location is determined primarily by the abundance of atmospheric ozone overhead: other factors being equal, it will vary in inverse proportion to the amount of ozone present.

Once it has penetrated the ozone layer, the amount of UV-B reaching the Earth's surface is affected most by the presence of clouds and the daily changes in the angle of the sun. Clouds absorb UV-B radiation and diminish the flux. Similarly, when the sun is low, its rays take a longer path through the atmosphere, causing greater attenuation of UV-B by water vapour, particulate matter, and other atmospheric constituents. At the equator, where ozone is least abundant, about 30% of the incoming UV-B reaches the Earth's surface. In high latitudes, where ozone is most abundant, the amount varies between 10% and 30% (depending on season and local conditions).

For humans, UV-B is beneficial in stimulating the synthesis of vitamin D in the skin. However, it hastens the aging of skin, and excessive exposure produces the familiar sunburn (erythema). More importantly, the incidence of skin cancers increases with increasing exposure to UV-B. The most persuasive evidence for this comes from epidemiological studies of the incidence of skin cancers in humans living at different latitudes and thus exposed to the natural north–south variations in UV-B (Fig. 23.9). The dose–response ratios that emerge enable reliable mathematical relationships to be established between UV-B exposure and disease under natural (i.e., unperturbed) atmospheric conditions.

There are several types of skin cancer. Basal and squamous cell carcinomas account for about 75% and 20% of the reported cases, respectively, and the much more serious malignant melanoma accounts for about 5%. For any given exposure, fair-skinned and fair- or red-haired people are most susceptible to malignant melanomas, particularly if they received a serious sunburn in early childhood. The incidence increases with exposure for all people, irrespective of their pigmentation. The U.S. Environmental Protection Agency (EPA) and others have suggested that a 1% decrease in stratospheric ozone would result in a 2% increase in UV-B and a 3–6% increase in skin cancer.

In the past few decades, many countries have reported increases in skin cancers, but it is difficult to be precise about how great the increase has been. Estimates of the number of new cases in Canada vary substantially. Health and Welfare Canada suggests a current figure of about 25 000 new cases of all forms of skin cancer, with nonmelanomas remaining fairly constant over the past 15–20 years. Melanomas, although still not common in Canada, have increased rapidly at an average rate of 5.5% annually between 1970 and 1984, making them second only to lung cancers in females in rate of increase (Y. DesLauriers, Health and Welfare Canada, personal communication). This represents an approximate doubling of the number of cases during this period (Cancer Information Service, Ontario, no date).

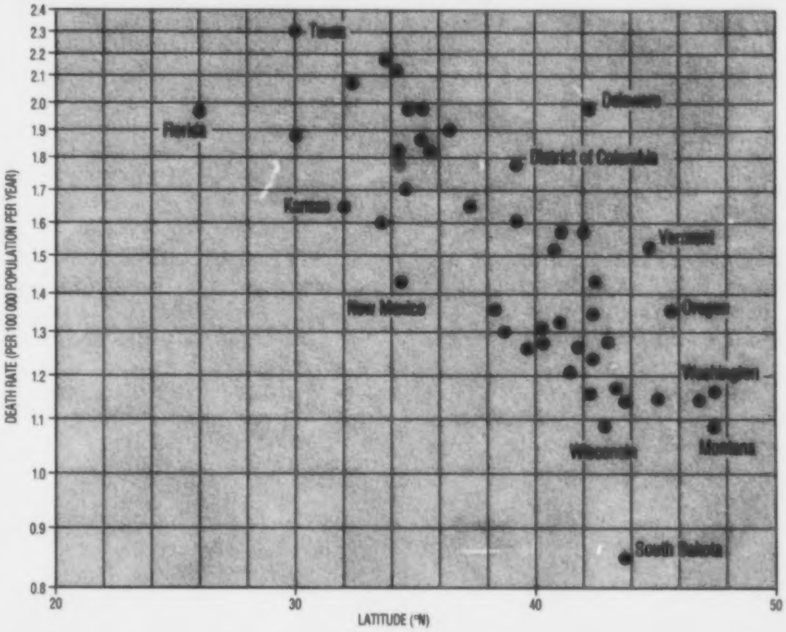
Excessive UV-B can also affect the eyes, causing damage to the retina and cornea. Cataracts are a common result of UV-B overexposure. The U.S. EPA has suggested that a 1% depletion in ozone could lead to a 0.3–0.6% increase in cataracts. This relationship, as in the case of skin cancer, has been derived by extrapolation from the variation of the disease with the normal geographic variation of exposure to ultraviolet radiation. There is no epidemiological evidence that eye disease has increased as a result of ozone depletion, and, in the absence of any evidence that UV-B flux to the surface has increased, this is not surprising.

UV-B radiation may also cause an increase in skin allergies and suppress the immune response, but this effect is poorly understood, and it is not yet possible to quantify the risk. It is possible that if the transmission of UV-B radiation to the surface increases, there could be a rise in the incidence and severity of opportunistic infections and those cancers associated with immune suppression.

Concern about the impact of increased UV-B levels extends as well to other animals and plants. Organisms exposed to sunlight at the Earth's surface and in shallow waters would presumably be directly at risk if UV-B increased. It is also possible that organisms that are not at risk from direct exposure could be vulnerable to indirect effects if key members of their ecosystem and food chain were affected.

FIGURE 23.8

U.S. melanoma cancer death rates, by latitude



Source: United Nations Environment Programme (1987).

All major ecosystems ultimately depend upon autotrophic plants — that is, plants that turn carbon dioxide and water into carbohydrates through photosynthesis. These primary producers of the food chain are commonly the familiar green plants, such as the trees of the forest, the grasses of the prairie, and the microscopic phytoplankton of rivers, lakes, and seas. Plants are usually adapted to a fairly narrow range of UV-B intensities and could be at risk if their exposure were increased beyond this range. It is not the absolute exposure to UV-B radiation that is important but the extent to which the normal exposure, and the inherent ability of the organism to adapt to it, is exceeded.

Even if the nature of ozone depletion and the extent and rate at which UV-B would increase could be confidently predicted, assessing the probability and severity of the risk to the world's ecosystems would be extremely difficult, as plants vary widely in their sensitivity to UV-B. In this regard, it is worth noting that many of the legumes (e.g., beans, peas, and soybeans), squashes, brassicas (e.g., cabbages and lettuces), and other food crops are extremely sensitive. A large number of the world's people depend upon legumes as a staple food, and these plants also play a key role in soil fertility through their ability to fix atmospheric nitrogen.

The more difficult problem is to determine how whole communities (ecosystems and biomes) would respond to increasing UV-B. Perhaps only a few sensitive species would be lost, and the overall impact would be little. But if these lost species were key members of the community — important as a component of the food chain or in preventing soil erosion or water loss — the result could be disastrous.

The marine food chains of the Antarctic are possibly the most vulnerable, because it is there that ozone depletion is most severe. The phytoplankton in the surface waters and immediately under the ice appear to be at the greatest risk because their major burst of growth occurs in the spring, when the ice is most transparent and antarctic UV-B levels are greatest (Voytek 1990). Researchers are divided in their assessments of the possible severity of the impact. Because the waters of the southern ocean are immensely productive and may account for up to one-fifth of the total biological productivity of the seas, there is a potential for catastrophic harm. However, a catastrophe seems less likely than a more subtle change in the ecosystem, with some species being replaced by others of greater tolerance to UV-B (Roberts 1989).

The situation with respect to other ecosystems is even less clear. The sensitivity of some species to enhanced UV-B is known, but there has not been any systematic research on the effects of small increases in exposure over long periods. How ecosystems and other living communities would respond to such changes, given their complexities, is poorly understood.

In summary, a great research effort is needed to enable more reliable estimates to be made of the ecological impacts of enhanced UV-B radiation on natural and managed ecosystems. With a doubling of the human population, on average, every 37 years, and the attendant problems of soil erosion, desertification, deforestation, and other stresses on agriculture and the subsistence base, the prospect of even a small depression in the productivity of natural ecosystems, forestry, fisheries, and agriculture must be regarded with concern.

HAS UV-B RADIATION INCREASED?

Theoretically, the depletion of stratospheric ozone should be reflected in a proportional increase in the amount of UV-B radiation now reaching the Earth's surface. But is there any evidence to confirm that such an increase has taken place?

In the Antarctic, calculations indeed suggest an association between an increased UV-B flux and the large ozone depletions that have been observed there. The amount of UV-B reaching the antarctic surface may now be greater in the spring, when the ozone depletion is most severe, than in the summer, when UV-B normally reaches its maximum in the region (Frederick and Snell 1988). If the situation were to worsen and the ozone depletion were to persist into the early summer when the sun is stronger, very large increases in UV-B might occur. It must be emphasized, however, that these are increases above the antarctic norm and are not necessarily large in absolute terms. The amount of UV-B reaching the antarctic surface would still be less than that which is normally received in the tropics.

Most of the reported fluxes in ultraviolet radiation have been calculated from the known depletion of ozone. This is not the same thing as making direct measurements. The values rely upon a number of assumptions about how the UV-B is transmitted and absorbed in the lower atmosphere, and there is growing evidence that some of these assumptions have been too simplistic. The few measurements that have been made do confirm that UV-B has increased in the Antarctic, but a systematic and comprehensive monitoring program, such as that recommended by the WMO, has not yet been implemented.

Measurements made in other parts of the world — in the low latitudes of the southern hemisphere and in the mid-latitudes of the northern hemisphere — have produced no evidence of a general increasing trend in the amount of ultraviolet radiation reaching the Earth's surface in recent years. Nine U.S. monitoring stations reported decreases or no increases in UV-B in the period 1974–85, with considerable variability between stations and no obvious trend (Grant 1988; Scotto *et al.* 1988*a*, 1988*b*). Similarly, the 4% decrease in column ozone over Toronto in the period 1975–87 was not accompanied by a commensurate change in UV-B (Evans *et al.* 1987).

Why, then, are we not seeing a clear correspondence between ozone trends and the amount of UV-B reaching the Earth's surface? One reason may be the limitations of the monitoring network itself, a result, in part, of the cost and technical difficulty of making the necessary measurements. Moreover, many of the instruments are located in urban areas where any possible effect of decreasing stratospheric ozone might be offset by increases in the levels of pollutants in the lower atmosphere. Rural stations routinely report UV-B levels that are about 6% greater than those recorded at urban locales. The situation would undoubtedly be clearer if a more adequate monitoring network were in place.

Another reason for the lack of a clear UV-B trend is that the changes that have been detected in global ozone are themselves quite small — less than 5% over about one and a half decades. In addition, there are good reasons to suppose that other changes in the atmosphere may have, to some extent, countered the effects of stratospheric ozone loss (Scotto *et al.* 1988*a*, 1988*b*). For example, levels of ozone and other ultraviolet radiation-absorbing pollutants, such as aerosols and particles and the gases nitrogen dioxide and sulphur dioxide, have been increasing in the troposphere. Water vapour in the atmosphere and the reflectivity of the Earth's surface also influence UV-B levels, and there are suspicions that these factors have been changing in response to other climatic changes (World Meteorological Organization/United Nations Environment Programme 1989).

One recent study has attempted to avoid the influence of the lower atmosphere by measuring fluxes of ultraviolet radiation high in the Alps, above the level where most particulates and other pollutants are abundant. The results suggest that there has been an annual increase in UV-B flux of about 0.7–1.1% between 1981 and 1989 (Blumthaler and Ambach 1990). Assuming that stratospheric ozone has been declining at less than 0.3% annually, the conventional estimate of a 2% increase in UV-B for every 1% decrease in stratospheric ozone may be reasonably valid, provided that the UV-B is not then attenuated by other factors as it passes through the troposphere.

There is therefore no conclusive evidence that the total ozone losses that have occurred so far have produced an increase in UV-B radiation at the Earth's surface, as predicted in early assessments. However, for large changes in ozone, such as those over Antarctica, the inverse relationship between ozone abundance and UV-B transmission is probably valid.

Because no significant increase in human exposure to UV-B has been detected, there are consequently no credible grounds for believing that ozone depletion has yet affected human health. Reports of a causal relationship between ozone depletion and the rising incidence of skin cancer, for example, have not attempted to explain how cancers could increase when there have been no general changes in the measured flux of UV-B to the Earth's surface. Nor do they appear to consider how the large increase in the number of these cancers could be caused by the small decline in ozone that has been measured at mid-latitudes, especially if it is true that a 1% decrease in ozone can lead to a 3–6% increase in cancer.

The causes of the apparent increase in the incidence of skin cancer cannot, therefore, be attributed at present to ozone depletion. Perhaps a more plausible explanation is to be found in the vastly increased popularity of southern holidays and suntanning in the decades after World War II. Given the increased awareness of the danger of overexposure to sunlight, however, the federal government's Green Plan (Government of Canada 1990) requires that the Canadian Ozone Monitoring Program be augmented to provide warning of UV-B for major Canadian cities, so that people can avoid excessive exposure.

It is equally doubtful that widespread biological impacts on other species could already have occurred. However, in view of the latest evidence that UV-B levels may have increased at high elevations, where there is little absorption and scattering by tropospheric pollutants, it may be that the first ecological impacts will be seen in alpine communities.

The possibility that the anticipated increase in UV-B at lower levels has been offset by changes in the troposphere gives little cause for optimism. Indeed, the effect may only be temporary and the respite illusory. These tropospheric changes are probably themselves indicators of an atmosphere perturbed by pollutants, and there can be no comfort in the knowledge that the effects of stratospheric pollution have been temporarily stayed through an insult to the lower regions of the atmosphere. Without global controls over the emission of ozone-depleting substances, it is likely that at some point the transmission of UV-B radiation to the surface will increase, with potentially serious consequences for human health and the well-being of natural ecosystems.

OZONE AND CLIMATE

Ozone plays a key role in the thermal structure of the atmosphere. In the stratosphere, it produces heat when it absorbs ultraviolet radiation from the sun and so helps to drive the wind currents of the upper atmosphere. In the troposphere, it absorbs infrared radiation from the Earth's surface and releases it again to the atmosphere, contributing to the warming processes of the greenhouse effect and influencing the movement of winds and weather systems in the lower atmosphere.

Because the ozone layer is, in a sense, one of the boiler rooms of the atmospheric engine, any large ozone depletion would cool the stratosphere. In response, the troposphere would become slightly warmer as ultraviolet radiation penetrated to lower altitudes and was absorbed there. The implications are difficult to predict, but there would almost certainly be an alteration in the radiative energy balance of the Earth. Such a change would upset the present circulation patterns of the atmosphere, causing a shift in weather and climate. We cannot say what level of ozone depletion would trigger these changes, but any large alteration in climate would have substantial social and economic repercussions, and some of these could be harmful. Ultimately, these indirect climatic effects of ozone depletion could prove to be as important as the direct impacts on human health.

Just as the abundance of stratospheric ozone in the atmosphere may affect climate, it is also possible that changes in climate may affect the abundance of stratospheric ozone. Two recent comprehensive reviews (Ozone Trends Panel 1988; World Meteorological Organization/United Nations Environment Programme 1989) agree that if carbon dioxide and other greenhouse gases cause a warming of the troposphere, there will be a cooling of the stratosphere. It is not clear, however, if this would aggravate or mitigate the problem of ozone depletion.

One possibility is that stratospheric cooling during the winter at high latitudes would promote the formation of PSCs and prolong the polar vortex, thus favouring the destruction of ozone in the polar and adjacent regions. But it is also possible that lower stratospheric temperatures could slow some chemical reactions, including those that deplete ozone. Models reviewed by the World Meteorological Organization/ United Nations Environment Programme study suggest that ozone depletion might be reduced by greenhouse warming. However, given the limitations of the models, a clear resolution of these two opposing tendencies is not yet possible.

Global warming and ozone depletion are further linked by the involvement of certain gases in both processes. Nitrous

TABLE 23.2

Ozone depletion scenarios and projections for 2060

Scenario: description	Ozone depletion (%) Tropics (total column)	High latitude (total column)	Mid-latitude (total column)	Global stratosphere (40 km)	Abundance of halogens Chlorine (ppbv)[a]	Bromine (pptv)[b]
1: No reduction CFCs and halons pegged at 1985 levels; methyl chloroform, carbon tetrachloride, and HCFC-22 increase at specified levels	1–4[c]	8–12		35–50	>9.2	>31
2: 50% reduction CFCs and halons pegged at 50% of 1985 levels by 2000, with 50% CFC replaced by HCFC-22; methyl chloroform, carbon tetrachloride, and HCFC-22 increase at specified levels	1.5–3.0	5–8		25–40	<7.2	<22
3: Major reduction/replacement CFCs and halons cut 95% from 1985 levels by 2000, with 50% CFC replaced by HCFC-22; methyl chloroform, carbon tetrachloride, and HCFC-22 increase at specified levels	No change		2–4	20–30	<5.4	<14
4: Major reduction/no replacement CFCs and halons cut 95% from 1985 levels by 2000, methyl chloroform and carbon tetrachloride pegged at 1985 levels, and no substitution of HCFCs for CFCs	No change	<4			3.6	14
5: Total ban 100% cut in CFCs, halons, HCFC-22, methyl chloroform, and carbon tetrachloride					1.9[d]	

[a] Current abundance of chlorine, 3.0 ppbv (parts per billion by volume).

[b] Current abundance of bromine, 12.5 pptv (parts per trillion by volume).

[c] Projections shown here do not consider the effects of global warming or of processes occurring in PSCs.

[d] Ozone depletion does not occur at this level.

Source: World Meteorological Organization/United Nations Environment Programme (1989).

oxide, CFCs, and halons are not only very effective destroyers of ozone but also powerful greenhouse gases. The commonly used CFCs and halons, for example, may contribute up to 24% of the warming effect induced by pollutants (Houghton *et al.* 1990).

In analyzing and responding to global warming and ozone depletion, it is therefore impossible to deal with one in isolation from the other. In terms of both causes and consequences, global warming and ozone depletion must be seen as interconnected aspects of the broader phenomenon of human-induced atmospheric change.

THE FUTURE: MANAGING THE STRATOSPHERE

How can we say what will happen in the future?

If the emission of chlorine and bromine from ozone-depleting compounds is abated, the abundance of stratospheric ozone must eventually return to normal values. The return will be eventual rather than immediate for a number of reasons, including the inevitable delay in instituting such controls. Also, much of the world's production of these compounds is still stored in fire-fighting equipment, air conditioning and refrigerating units, and foams. Releases from these banks could continue far into the future. The most important factor, however, is the very substantial atmospheric lifetimes of these substances, which will continue to exert their effects long after they have been released. The critical issue is whether these emissions can be abated and the effects of these controls felt before serious, and possibly irreversible, harm occurs.

Computer simulation models of the physical, dynamical, and chemical behaviour of the atmosphere offer a powerful tool for analyzing future scenarios. Through them, researchers can ask a series of "what if" questions about the possible impacts of various options or test their understanding of how various physical and chemical processes affect each other. Valid and invalid assumptions can be identified, strategies evaluated, and the benefits of controlling various substances compared.

Table 23.2 summarizes the results of a study by a World Meteorological Organization/United Nations Environment Programme (1989) working group, which modelled various scenarios for controlling several major ozone-depleting compounds. For each of these scenarios, the model projected the total ozone changes that would occur at various latitudes as well as the changes that would occur globally within the stratosphere at an altitude of 40 km. The results of the study showed that even if emissions were frozen at 1985 levels (Scenario 1), the abundances of chlorine and bromine in the atmosphere would triple by the year 2060. Such an increase could cause depletions of total ozone to approach 4% in the tropics, 12% in the high latitudes, and perhaps up to 50% globally in the upper portion of the stratosphere.

With increasing controls, the depletions became less severe. However, the model also suggested that to reduce atmospheric chlorine levels to less than 2 ppbv — the level at which antarctic ozone would be expected to return to normal — the complete elimination of CFCs, halons, carbon tetrachloride, methyl chloroform, and HCFC-22 (a hydrochlorofluorocarbon) might be necessary.

Can we manage without ozone-depleting chemicals?

The demand for ozone-depleting chemicals and for the processes and equipment that use them is substantial. Just how substantial can be seen from industry statistics. CFC production and use in the United States alone involve 5 000 companies at 375 000 locations, employ more than 700 000 people, and produce goods and services worth $28 billion (various sources, cited in Manzer 1990). Proportionate levels of use, investment, and employment occur in the other developed nations. No similarly detailed analysis is available for Canada, but there are close to 40 major manufacturers using CFCs (Corpus 1989) for more than 160 specific uses (Du Pont Canada Inc. 1988). Moreover, in developing countries, where CFC usage was once minimal, the requirements of rapid industrialization and a growing demand for refrigerated foods have led to an increase in the consumption of ozone-depleting chemicals.

Even if society could stop using these compounds for apparently trivial uses such as aerosol sprays, packaging, and upholstered furniture, other more legitimate needs, such as refrigeration, air conditioning, insulation, and fire fighting, will remain (see Box 23.1). Because these demands cannot be eliminated, the problem becomes one of finding ways to deliver these services through means that do not deplete stratospheric ozone and do not introduce yet new risks to the environment or human health.

Although conversion to non- or low-ozone-depleting alternatives will also create growth and employment, some economic and industrial dislocation and costs will be entailed (Pool 1988; Manzer 1990); as with any attempt at economic forecasting, there is considerable debate over just how serious these will be. Despite the difficulties, concern over the integrity of the ozone layer has led to a broad-based interest in phasing down and phasing out ozone-depleting compounds and searching for more benign alternatives.

Some industry estimates suggest that conservation (recovery, recycling, reclamation, and improved plant maintenance) will reduce CFC use by 29% by the year 2000 and that a further 30% reduction will be achieved by using non-CFC replacements. These include the use of aqueous and organic compounds as cleaning agents in the electronics industry and carbon dioxide and organic gases as blowing agents in foam manufacture. At least 40% of the market will continue to require halocarbon products, although these will be compounds that are less destructive to the ozone layer than those now in use (Manzer 1990).

Replacements: HCFCs, HFCs, and HCs

Hydrochlorofluorocarbons (HCFCs) (see Box 23.2) and hydrofluorocarbons (HFCs) are the most immediately promising replacements for CFCs. These compounds, although similar in many respects to CFCs, also contain hydrogen. Because carbon and hydrogen form a much less durable bond than carbon and the halogens, significant quantities of these compounds are broken down by sunlight and chemical processes before they can be carried into the stratosphere. Because they contain chlorine, however, HCFCs remain a threat, albeit a much diminished one, to the ozone layer. HFCs contain no chlorine and have no potential to deplete stratospheric ozone.

The main problem with these substitutes is that the further their chemical structures depart from those of the compounds they are intended to replace, the less likely they are to have

BOX 23.1

CFCs in the home

Most Canadian households have appliances containing ozone-depleting substances. Refrigerators contain about 0.2–0.3 kg of CFCs, freezers about 0.3–0.5 kg, and central air conditioning units and heat pumps about 13.5 kg. About 60% of all new vehicles sold in Canada, and about 90% in the United States, have air conditioning. A typical unit in a passenger car or a small commercial vehicle contains approximately 1.4–2.0 kg of CFCs. In addition, most upholstered furniture contains flexible foam, and more modern homes contain appreciable quantities of rigid foam insulation, all of which are blown with CFCs.

the required characteristics and the greater are the difficulties and costs associated with their use. Most replacement refrigerants, for example, are less efficient than CFCs and have to be pumped at higher pressures. They also generate greater temperatures, make more noise, require stronger hoses and compressors, and are not compatible with the materials used for seals or the currently used lubricants.

From the fall of 1993, General Motors of Canada will be charging all its new air conditioning units with HFC-134a, but the change has necessitated a complete redesign of the systems. Given the limited usable life of a motor vehicle, the costs may be relatively easy to absorb. In contrast, for the conversion of large commercial refrigeration and air conditioning systems, which are already expensive and are expected to have a service lifetime of decades, the costs may be extremely high. However, advances have been made, particularly using mixtures of HCFCs. Most domestic air conditioners are now using HCFCs, and more substitute compounds will be in use in the near future. HCFC-22 is already in use in refrigeration and air conditioning, and HFC-134a and HFC-152a show promise as replacements for CFC-12, although HFC-152a is flammable, and both require modified mechanical components (Pool 1988; Manzer 1990).

Rigid foams produced with HCFC and HC (hydrocarbon) blowing agents are generally considered to have relatively poor insulating properties. Their use therefore entails increased energy consumption, which also has an adverse environmental impact. HCFC-141b, HCFC-152a, and HCFC-123 (on their own or in blends) show promise as replacement blowing agents, and one manufacturer claims that its new HCFC-blown foam has the same insulating properties as its product manufactured with CFCs. HCFC-123 has considerable potential as a blowing agent and is currently undergoing environmental toxicity tests for anticipated

BOX 23.2

Ozone-depleting chemicals

Most of the major ozone-depleting chemicals are halocarbons, a group of compounds formed from carbon and one or more members of the halogen family (e.g., chlorine, bromine).[1] Their threat to stratospheric ozone derives from two characteristics. One is the propensity of the halogens to catalyze ozone-destroying reactions. The other is the strength of the chemical bond between carbon and halogen atoms, which gives these compounds their stability and allows them to survive in the atmosphere long enough to reach the stratospheric ozone layer.

The ozone-destroying power of a compound is called its Ozone Depletion Potential (ODP). It compares the destructive power of the compound with that of CFC-11, which is given an ODP of 1.0.

Chlorofluorocarbons (CFCs)

Compound	Formula	ODP	Atmospheric lifetime (years)
CFC-11	$CFCl_3$	1.0	60
CFC-12	CF_2Cl_2	1.0	120
CFC-113	$CF_2ClCFCl_2$	0.8	90
CFC-114	CF_2ClCF_2Cl	0.6–0.8	200
CFC-114a	CF_3CFCl_2	n.a.	n.a.
CFC-115	CF_3CF_2Cl	0.3–0.5	400

n.a.= not available

Global emissions (CFCs 11, 12, and 113): approximately 800 000 t annually. Atmospheric abundance (CFCs 11, 12, and 113): 0.7 ppbv. Rate of increase: 5–6% annually. Contribution to total ozone depletion: more than 80%.

CFCs were synthesized in the 1890s and, following the development of CFC-12 in 1928, became widely used as refrigerants, replacing a number of toxic and flammable compounds then in use. Since then, CFCs with other properties have been developed for a variety of uses, principally as blowing agents in the manufacture of polystyrene and polyurethane foams, as propellants for aerosol sprays, and as solvents and cleaning fluids, particularly in the electronics industry.

By the early 1980s, the use of CFCs as aerosol propellants had been banned in Canada, the United States, and Scandinavia for all but essential uses. However, this decrease in usage was offset by the increasing use of CFCs for other applications. In addition, aerosol applications remained high in other parts of the world.

Twenty-five countries produce CFCs, but five of them account for 75% of the world's production, the United States and the United Kingdom being the most important. Canada accounts for less than 3% of world production. By 1987, annual global consumption of CFCs exceeded 1 million tonnes. Canadian consumption was about 20 000 t annually during 1986–87, but this had fallen to approximately 16 000 t for the period from July 1989 to July 1990. Global CFC consumption by region is shown in Figure 23.B1.

Halons

Compound	Formula	ODP	Atmospheric lifetime (years)
Halon-1211	CF_2BrCl	2.2–3.5	25
Halon-1301	$CBrF_3$	7.8–16	80–110
Halon-2402	$C_2F_4Br_2$	5.0–6.2	23–28

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[1] The halogen fluorine is not a threat to the ozone layer because fluorine radicals quickly combine with other elements to form new compounds and thus are unavailable to react with ozone.

[illegible]

Annual global production (halons 1211 and 1301): more than 21 000 t. Annual global emissions (halons 1211 and 1301): 6 000 t. Atmospheric abundance: 0.0037 ppbv. Rate of increase: 11–15% annually. Contribution to total ozone depletion: 5%.

Halons are primarily used as fire suppressants. Probably 70% of all halons ever produced are now stored in fire extinguishers and fire control systems and may ultimately be released to the atmosphere. Their efficiency has led to universal application in fire control for aircraft. They also provide fire protection for expensive and delicate equipment and materials (e.g., computer installations and libraries), which would be damaged by water, foam, and other substances. Halon consumption in Canada has quadrupled from approximately 200 t in 1980 to 800 t in 1988.

Carbon tetrachloride

Formula: CCl_4. ODP: 1.1. Atmospheric lifetime: 50 years. Annual emissions: 66 000 t. Atmospheric abundance: 0.14 ppbv. Annual rate of increase: 1.5%. Contribution to total ozone depletion: less than 8%.

Carbon tetrachloride is used as an industrial solvent, an agricultural fumigant, and a chemical intermediate in a large number of industrial processes (e.g., petrochemical refining). Worldwide, more than 90% is used in the manufacture of CFCs and similar chemicals. In the past, large quantities were vented to the atmosphere after use in dry cleaning, but carbon tetrachloride has been banned in North American and western European cleaning industries for some years, and most of the current emissions emanate from eastern Europe. The Canadian net domestic supply was 20 100 t in 1989 and has remained relatively stable since the late 1970s. Of this, Environment Canada reports that considerably less than 0.5% is likely to be emitted to the atmosphere in the form of carbon tetrachloride.

Methyl chloroform

Formula: $C_2H_3Cl_3$. ODP: 0.15. Atmospheric lifetime: 6 years. Annual global emissions: 474 000 t. Atmospheric abundance: 0.15 ppbv. Estimated annual increase: 4%. Contribution to total ozone depletion: 5%.

Although methyl chloroform breaks down in the troposphere, it remains a concern because it is produced in large quantities and because its use as a metal cleaning agent means that much of it is vented to the atmosphere. Canadian net domestic supply in 1989 was approximately 16 300 t, up from 12 500 t in 1977.

Hydrochlorofluorocarbons (HCFCs)

Compound	Formula	ODP	Atmospheric lifetime (years)
HCFC-22	CHF_2Cl	0.04–0.06	15–20
HCFC-123	CF_3CHCl_2	0.02–0.16	1–2
HCFC-141b	CH_3CFCl_2	0.03–0.11	6–11
HCFC-124	CF_3CHFCl	0.016–0.024	5–10
HCFC-225ca	$CF_3CF_2CHCl_2$	n.a.	n.a.
HCFC-225cb	$CFHClCF_2CF_2Cl$	n.a.	n.a.

n.a.= not available

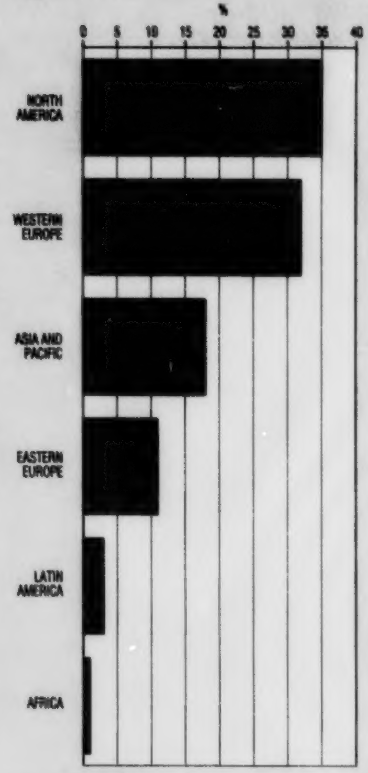
Annual global emissions (HCFC-22): more than 70 000 t. Atmospheric abundance (HCFC-22): 0.1 ppbv. Annual rate of increase (HCFC-22): 7–10%. Contribution to total ozone depletion (HCFC-22): less than 0.5%.

Hydrochlorofluorocarbons (HCFCs) are important primarily as replacements for CFCs. HCFC-22 is the most important, having been used for some time as a replacement, and now as the chemical of choice, in some air conditioning, heat pump, refrigeration, and foam-blowing applications. Although HCFCs have been sanctioned under the Montreal Protocol and will be the fluorocarbons of choice probably into the next century, they are still ozone-depleting chemicals and must be regarded as temporary replacements.

Source: Hammitt *et al.* (1987); Pool (1988); Corpus (1989); Forester *et al.* (1989); World Meteorological Organization/United Nations Environment Programme (1989); Manzer (1990); and industry sources.

[illegible]

Global consumption of CFCs by region, 1987



Source: United Nations Environment Programme (1989).

production in 1993. Some of these replacements are also flammable, increasing the manufacturing hazard and necessitating costly process changes. Their deficiencies can probably be offset by improved, more efficient designs and by closer attention to process engineering at the manufacturing stage.

CFCs used for cleaning electronic components (notably microchips and printed circuit boards) are gradually being replaced by nonhalogenated and water-soluble agents. Because these do not always produce as high a standard of cleanliness, they have met with some resistance from the industry and its clientele. However, components cleaned by replacement substances are being rigorously evaluated in joint military, governmental, and industrial trials. It is expected that they will meet the functional requirements and that resistance to their use will diminish. Water-based cleaning agents also leave a contaminated waste stream that must be treated before it can be discharged.

Several companies have recently announced replacements for halon-1211 and halon-1301 for use in fire control systems, but the properties, behaviour, and liabilities of these compounds have yet to be evaluated.

Industry and governments have cooperated to ensure that an ordered and equitable transition to replacements occurs. One problem that remains, however, is that some substitutes, such as HCFCs, although far less damaging than the compounds they replace, still pose some threat to the ozone layer. Industry has sought confirmation that these will be sanctioned even though they are not completely benign. For governments, the choice is to accept some less-than-perfect interim substances or to delay the transition from CFCs until ideal replacements (i.e., alternatives to the HCFC alternatives) become available. Such a delay would require that potent ozone-depleting substances remain in use longer. The signatories to the Montreal Protocol on Substances that Deplete the Ozone Layer have now sanctioned HCFCs as acceptable, temporary replacements for many CFCs, and they will doubtless be the mainstays until completely benign technology is developed.

Not-in-kind replacements

Although far less destructive than CFCs, many of the replacements still have an appreciable impact on ozone. Furthermore, HCFCs, HFCs, and HCs are all greenhouse gases, and their contribution to global warming could be even more environmentally harmful than their effects on ozone. Consequently, there has been considerable interest in developing so-called "not-in-kind" replacements that are environmentally benign in terms of both ozone depletion and climatic warming. This trend will probably result in the use of paper products as a replacement for some foam food containers. Some of the flexible foam used in furniture will be replaced by materials that are not made with blowing agents. Similarly, less efficient but environmentally benign fibreglass materials and possibly also vacuum panels will likely come into increasing use as an alternative to blown plastic foam insulation.

Recovering, recycling, reusing, and retraining

During the transition to replacement products, it will be important to recover, recycle, and reuse the powerful ozone-depleting chemicals that remain in use. This will be necessary not only to protect the environment but also because some demand for these chemicals will continue after their manufacture has ceased. For example, although General Motors of Canada will switch to replacement air conditioning fluids at the end of 1993, the company intends to service vehicles using CFC-12 until the turn of the century and has installed recovery equipment in all its Canadian service centres. Ford Canada has taken similar action. Nissan has also announced its intention to recycle CFC-12, and other car companies are expected to do likewise.

Cleaning solvents have usually been vented into the atmosphere after use, but many major corporations are now undertaking recovery and recycling programs, and specialized industries have emerged to undertake this service. It has also been customary practice to vent refrigerants from commercial and residential air conditioning units into the atmosphere during service, but this practice is beginning to change, and the more responsible agencies are now recycling.

Unnecessary releases of CFCs often occur during the manufacturing and testing of air conditioning and refrigeration equipment. Similarly, testing and fire-fighting training account for a significant portion of halon releases. In fact, only about one-quarter of all halon-1301 emissions to the atmosphere result from their use in fires. Industry and users have now revised many of their procedures to minimize such losses (Forester *et al.* 1989). In the air conditioning industry, for example, environmentally benign gases are increasingly used for flushing units and testing for leaks. Until recently, this was commonly done with CFCs, which were then vented to the atmosphere.

The growing environmental awareness of industry, the service sector, and users, coupled with changes in operational procedures and appropriate legislation, will help reduce these unnecessary emissions significantly. To this end, the federal Green Plan (Government of Canada 1990) has announced a new program of cooperation with the provinces to promote the conservation, recovery, and recycling of the major ozone-depleting compounds.

GOVERNMENTAL ACTION

In March 1985, representatives from 20 governments around the world signed the Vienna Convention on the Protection of the Ozone Layer. The agreement called for cooperation in the areas of research, monitoring, and exchange of information, but it carried no specific commitment to control. When the antarctic ozone depletion was reported shortly afterwards, it was clear that there was an immediate need for more decisive and far-reaching action. In September 1987, the international community responded with the Montreal Protocol on Substances that Deplete the Ozone Layer and, for the first time, set out specific control measures.

The Montreal Protocol

The Montreal Protocol required its signatories to cut CFC use by 50% before mid-1998 and to freeze halon use at the 1986 level by 1992. It also addressed the need to phase down and phase out ozone-depleting substances in the immediate term and to continuously assess the status of relevant scientific knowledge over a longer period.

TABLE 23.3

The Montreal Protocol: revised control measures

Year	CFCs identified in protocol	Other CFCs	Halons identified in protocol	Carbon tetrachloride	Methyl chloroform
1992	freeze	—	freeze	—	—
1993	20%	20%	—	—	freeze
1994	—	—	—	—	—
1995	50%	—	50%	85%	30%
1996	—	—	—	—	—
1997	85%	85%	—	—	—
1998	—	—	—	—	—
1999	—	—	—	—	—
2000	100%	100%	100%	100%	70%
2005					100%
Base year	1986	1989	1986	1989	1989

Notes:

1. The adequacy and feasibility of further control measures will be considered at a meeting of parties to the protocol in 1992. A decision on essential uses of halons will be made by the parties on January 1, 1993.
2. HCFCs are to be phased out between 2020 and 2040. In the interim, their usage is to be confined to CFC substitutes.
3. Other halons are not used much commercially. Studies are under way through the Montreal Protocol to determine whether — and, if so, how — they can be included in the protocol.

Source: Environment Canada, Atmospheric Environment Service.

Its provisions required the placing of controls on CFCs 11, 12, 113, 114, and 115, which account for approximately 70% of the stratospheric ozone depletion, and halons 1301, 1211, and 2402. No restrictions were placed on carbon tetrachloride and methyl chloroform. The protocol divided the ozone-depleting chemicals into two groups (Group I, the CFCs; Group II, the halons) and established the Calculated Level of Production (CLP) for each group by multiplying the annual production of the various chemicals by their Ozone Depletion Potentials (ODPs). The CLPs for each group were then added together. In this way, each country was given the flexibility to adjust its production and use of ozone-depleting substances in the most convenient manner for itself as long as it remained within its CLP. Trade in ozone-depleting chemicals with nonsignatories was prohibited, so that the provisions of the protocol could not be circumvented.

Some 24 countries originally signed the protocol, which came into force on January 1, 1989. Canada was one of the first of many nations to ratify it. However, even at the time of its drafting, there was an awareness that its requirements were already inadequate. Consequently, the Montreal initiative has continued with meetings in Helsinki in 1989 and in London in 1990, at which the control provisions were refined, tightened, and expanded to include methyl chloroform, carbon tetrachloride, and various other substances (Table 23.3). The major industrialized countries have now agreed to phase out production of CFCs and halons by the year 2000 and methyl chloroform by 2005. The importance of HCFCs as bridging chemicals has been recognized and their use as CFC substitutes sanctioned until 2020–2040.

Canada made an individual commitment to ban CFCs by 1997 and methyl chloroform by 2000, ahead of the protocol's requirements. The House of Commons Standing Committee on the Environment (1990), concerned about the global warming potential of HCFCs and HFCs, also urged that these not be substituted for CFCs in amounts greater than 30% and 9%, respectively.

Developing countries face special problems in reducing and eliminating ozone-depleting chemicals. Not only is cost a formidable factor for them, but they also face a growing demand for refrigeration as a result of their warm climates and growing populations. India and China have argued forcefully that, because the industrialized nations have benefited from the use of ozone-depleting compounds, they now have obligations towards poorer nations that have done comparatively little to harm the stratosphere and yet are now being asked to forego these benefits and assume the costs of environmental protection for the common good. They have also argued that most developing countries are currently using ozone-depleting chemicals at levels that would be environmentally sustainable if adopted globally.

In response, it has been agreed that signatory nations whose annual per capita consumption of ozone-depleting chemicals is less than 0.3 kg will be allowed a 10-year period of grace beyond that permitted the industrialized world to implement the phaseout. The developed nations have also agreed to contribute U.S.$160 million in the three-year period to 1994 to a central fund, called the UN Montreal Protocol Multilateral Fund, to assist developing countries in reducing their dependence on ozone-depleting chemicals. The money will also be used to support the search for effective substitutes and for undertaking case studies on conversion from CFCs. Canada will contribute up to $7 million to the fund and will contribute to the funding of its secretariat, which will be based in Montreal.

Federal programs and Canada's Green Plan

In December 1990, the federal government released *Canada's Green Plan* (Government of Canada 1990), a comprehensive environmental protection plan involving scientific and technological programs, public information initiatives, legislation, regulations, and inter- and intranational cooperative ventures. Under the plan, Canada will participate in research programs with the United States, the Soviet Union, Japan, and the European nations to develop solutions to the problem of ozone depletion. The reader is referred to the Green Plan for a detailed summary of how the ozone protection initiatives relate to the overall government policies and strategies for environmental protection.

SUMMARY AND CONCLUSION

Scientists can now confidently link stratospheric ozone loss to the presence of powerful ozone-depleting gases in the atmosphere. These gases — CFCs, halons, methyl chloroform, and carbon tetrachloride — are of human origin, and their abundance in the atmosphere is increasing at a rapid rate and on a global scale. Although there is no evidence that the depletion of stratospheric ozone has as yet had measurable effects on human health or on natural ecosystems, the possibility of such damage becomes greater as ozone losses increase.

But the significance of our depletion of the ozone layer goes beyond these potential biological hazards. For the first time in the history of the planet, human beings have precipitated a major geophysical disturbance on a global scale — a disturbance that will continue for perhaps another century, even if we take remedial action now. We have done this inadvertently, within the space of a few decades, and we cannot be certain what its real impact will eventually be.

Nevertheless, we have begun to make substantial progress in understanding the crisis that faces us. In barely 15 years, Molina and Rowland's (1974) controversial hypothesis about the effects of CFCs on the ozone layer has become accepted. But, as with most complex environmental issues, the glass is both half full and half empty: we know a great deal, but we need to know a great deal more. The discrepancy between our knowledge and our ignorance, and how we place it in perspective, is also part of the problem. It means we are obliged to make extremely serious decisions on how to manage the environment in spite of continuing uncertainty. There is never proof beyond all doubt in these matters. We are spurred to find out more, but we risk being paralyzed into inactivity while the quest goes on. Although we may not necessarily come up with the best solutions, we might realistically expect to avoid some of the worst. It is well to remember, too, that we are not allowed the luxury of abstentions — to do nothing at all is, in itself, a serious and probably disastrous option.

As individuals, communities, and polities, we have to exercise prudence and informed judgement, recognizing that the uncertainty may work in both ways — the atmosphere may be more resilient to the insult by chlorine and bromine than we think, but it is also possible that stratospheric ozone may be in even greater jeopardy than we have predicted. The massive and unexpected loss of ozone over the Antarctic should remind us that it is not prudent to be complacent or optimistic.

As one leading researcher has said, "The possibility that the stratospheric ozone layer could be depleted by half at certain latitudes and seasons would have been deemed a preposterous and alarmist suggestion in the early 1980s" (Solomon 1990). But in the story of our unpreparedness, there is the seed for hope, for she continues, "A decade later the statement is acknowledged as proved beyond reasonable scientific doubt," and governments, recognizing that the evidence could no longer be ignored, have translated concern into action through the Montreal Protocol.

Most informed people now believe that there is a real risk that ozone will be depleted globally in sufficient quantity to harm life at the Earth's surface. This belief has come to be shared by governments as well. Even if some uncertainty remains, a significant start has been made.

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24

COURTESY OF ATMOSPHERIC ENVIRONMENT SERVICE, DOWNSVIEW

HIGHLIGHTS

Around the world, it is natural for rainfall to be slightly acidic, but in eastern Canada the rain has been found to be 10 times more acidic than normal.

■

The quantities of acid-forming pollutants that are emitted in North America are staggering. In 1980, Canadian smelters and fossil-fuel-burning vehicles and power plants produced about 4.6 million tonnes of sulphur dioxide and 1.8 million tonnes of nitrogen oxides; the equivalent amounts in the United States were 24 million and 20 million tonnes, respectively.

■

Studies indicate that as much as 50% of the acid-forming substances that fall on eastern Canada originate in the industrial heartland of the midwestern United States and are transported to Canada by air currents.

■

Acid-forming substances react in complex ways with physical and biological components of the ecosystem. Increased acidity poisons lakes and streams, releases toxic levels of metals into the ecosystem, corrodes brick and stone, causes impaired lung function and complications in sensitive individuals, leaches nutrients from the soil, may reduce agricultural productivity, and contributes to forest dieback.

■

Four million square kilometres (i.e., 46% of Canada's land area) has little capacity to buffer acidity with alkaline compounds, and the waters there are considered to be highly sensitive to the ecological effects of acidification. Much of the highly sensitive land is east of Manitoba, in the regions where levels of acidic pollutants are highest.

■

Canada and the United States have agreed to seek to reduce acid-causing emissions to as little as half the 1980 quantities. By 1990, overall emissions, primarily in eastern Canada, had been reduced by 40% of the 1980 levels.

■

Since 1970, the overall amount of acidic sulphur falling on eastern Canada has declined steadily. It has been established that reduction of sulphur emissions does result in improved aquatic habitat.

■

Even achieving the target of a 50% reduction from 1980 emission levels will not wholly protect eastern Canada's most highly sensitive lands and waters. Some lakes will still be at risk. The implications for forestry and other resources are not well understood.

■

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> “The first signs of long-range ecological damage from these pollutants appeared in Scandinavia during the sixties, with reports of dwindling fish populations in lakes. Soon thereafter it was found that in some bodies of water all aquatic life was disappearing.”
>
> — Brown *et al.* (1988)

INTRODUCTION

During the 1980s, “acid rain” became, for many Canadians, a definitive symbol of environmental crisis. Few might understand fully the causes and effects of the problem, but one fact was alarmingly clear to all: if something was wrong with the rain, it would affect everyone.

This was no local problem. Rather, the threat mocked provincial and national boundaries and struck to the heart of global issues of sustainable resource use and economic development. Successful solutions would demand a broad spectrum of scientific, political, and administrative expertise, applied within an unprecedented framework of peacetime cooperation between governments, corporations, and research institutions.

In the early 1980s, the “war” against acid rain was largely waged on fronts such as deteriorating water quality and diminishing fish populations. The acidification of supposedly pristine lakes in the Canadian Shield offered an arresting image. Despite the fact that acidic deposition affects more than lakes, the image of the biological death of lakes in remote wilderness was a useful focal point for garnering public support for the complex task of negotiating emission standards and other corrective measures. By the middle of the decade, however, the public realized that, in all likelihood, much more than aquatic life was at stake.

Even scientists do not yet understand exactly how much more. Canada has a wealth and diversity of natural resources, which makes it an enormous task to decipher the full effect of acidification in this country. Researchers have advanced their understanding of the impact of acidic deposition on surface waters and fisheries, but their comprehension of its effects on forestry, agriculture, and human health is still limited. This makes it difficult for decision-makers in government and in business to make comprehensive assessments of risks and benefits in situations where acidic deposition is a factor.

THE PROCESS OF ACIDIFICATION

Recognizing the problem

More than a century ago, Robert Angus Smith, a British chemist, coined the term “acid rain” (Smith 1872), and, despite the limitations of a technology that was primitive by today’s standards, he demonstrated that smoke and fumes contained substances that caused significant changes in the chemical composition of precipitation, changes that could be detected not only close to the source, but also “in the fields at a distance.” He also identified some of the harmful effects of “acid rain,” such as the bleaching of coloured fabrics, the corrosion of metal surfaces, the deterioration of building materials, and the dieback of vegetation.

In Canada, acidic deposition was not identified as an environmental concern until the 1950s. Working at Dalhousie University in 1955, Dr. Eville Gorham attributed the “abnormal acidity” that he detected in precipitation, and in the water of Nova Scotia lakes, to airborne pollutants which, he theorized, might come from distant sources. Surface water surveys and monitoring that had been undertaken by the Canada Department of Mines and Technical Surveys (Thomas 1953) provided a valuable baseline for early documentation of the trends and consequences of acidification.

In 1966, Dr. Harold Harvey, at the University of Toronto, detected severe losses among fish populations in the lakes of the La Cloche Mountains, southwest of Sudbury, Ontario, and ascribed these losses to acidification of the waters by acid rain (Beamish and Harvey 1972). Two large research programs, the International Joint Commission’s reference reports on the upper Great Lakes (International Joint Commission 1982) and the Sudbury Environmental Study undertaken by the Ontario ministries of Environment and Natural Resources (Ontario Ministry of the Environment 1979), both produced reports that identified this state of abnormal chemistry in precipitation falling on Ontario lands and waters.

Such research findings, backed by others from abroad, prompted the convening of a symposium in 1975 to address the "Atmospheric Contribution to the Chemistry of Lake Waters" (Matheson and Elder 1976). In May 1976, Environment Canada directed the formation of a committee of scientists to study the long-range transport of airborne pollutants (LRTAP). The report of this group (Whelpdale 1976) stated that:

> "...in Canada, the potential for problems of this nature exists. We have the meteorological conditions which are conducive to transport from source regions in Canada and the United States to regions of the country which have sensitive soils, waters, fish and forests."

What is "acid rain"?

In the popular media, the term "acid rain" has been used very loosely. Technically, acid-forming and acidic pollutants are transported and deposited via the atmosphere, not just in the form of rain, but as snow, cloud, and fog ("wet" types of deposition) as well as gases and dust ("dry" types) during dry periods. When we want to refer broadly to all these different forms, the term "acidic deposition" is more appropriate than "acid rain."

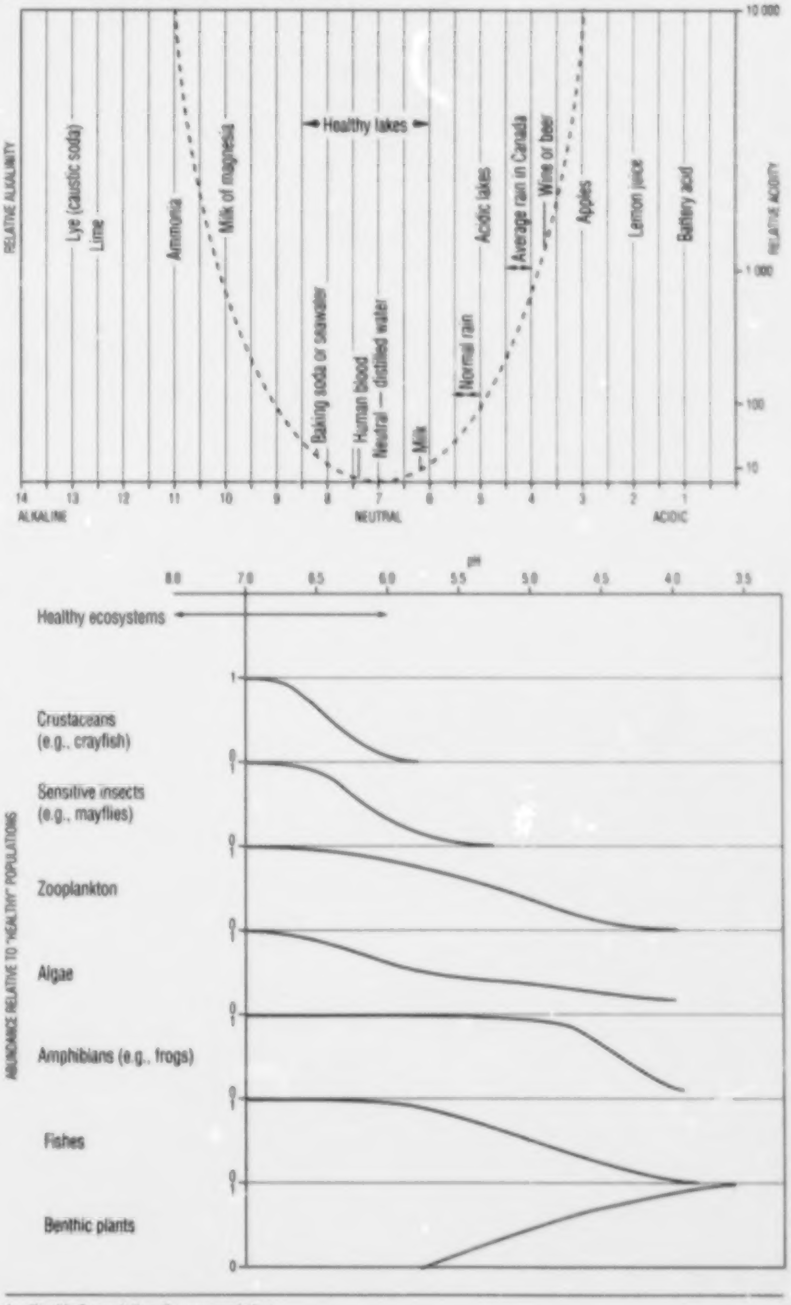
Around the world, normal precipitation is slightly acidic, with a pH of approximately 5.6–5.0 (Fig. 24.1). This modest amount of acidity comes from the absorption of carbon dioxide and other acidic material of natural origin. In some areas, the pH value of precipitation may exceed 5.6, as in the Prairie provinces, where wind-blown alkaline soil materials actually reduce the natural acidity levels.

However, precipitation over eastern North America, and much of Europe as well, has been found to be 10 times more acidic than normal, largely because of the incorporation of airborne sulphur dioxide (SO_2) and nitrogen oxides (NO_x) (Fig. 24.2). These human-

FIGURE 24.1

The pH scale

The range of relative acidity can be illustrated by comparing common substances from everyday life. Acidity is generally measured in terms of pH, on a scale that runs from 0, the most acidic, to 14, the most alkaline. Each major point on the scale represents a 10-fold change in acidity (i.e., pH 4 is 10 times more acidic than pH 5). At the midpoint of this scale, pH 7 represents a neutral balance. Organisms generally thrive near the neutral point and function less successfully toward either end of the scale. Trout, for example, thrive in water with a pH reading between 7 and 6. At pH 5.5, they exhibit reproductive problems, and below pH 5.0, they cannot usually survive.

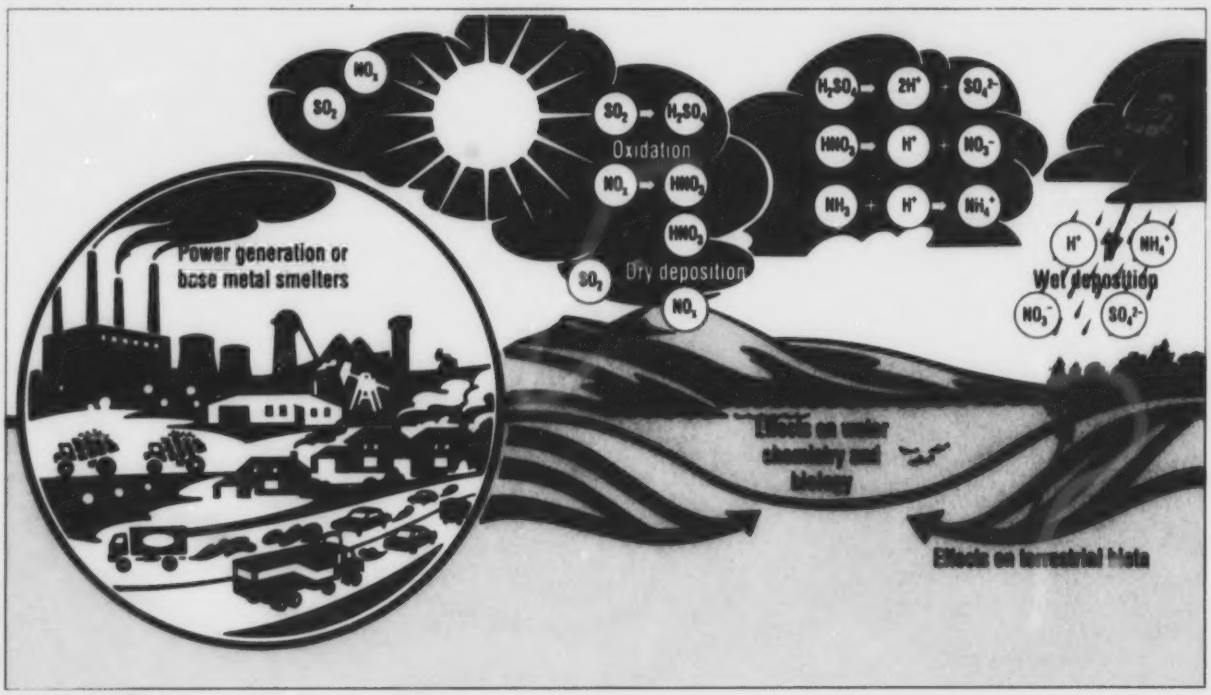


1 = "healthy" population, 0 = no population

FIGURE 24.2

A simplified diagram of the sources and the atmospheric transfers of acidic pollutants

The human-caused substances that trigger the phenomenon are sulphur dioxide (SO_2) and nitrogen oxides (NO_x). Complex chemical processes in the atmosphere and on the ground transform them into sulphuric acid (H_2SO_4) and nitric acid (HNO_3).



Source: Gorrie (1986).

caused gases react in complex ways to form sulphuric and nitric acids in the atmosphere — in rain, snow, and cloud droplets. Oxides of sulphur and nitrogen may reach the earth directly as gases or dry particulates and react to create acidic conditions. Thus, both pollutants add acidity to the clouds and precipitation; cloud droplets have had pH levels as low as 2.6 when measured at Whiteface Mountain in New York state (Castillo 1979).

Sources of acid-forming pollutants

Although natural sources of sulphur oxides and nitrogen oxides do exist, more than 90% of the sulphur and 95% of the nitrogen emissions occurring in eastern North America are of human-made origin. The largest sources of these pollutants are the smelting or refining of sulphur-bearing metal ores and the burning of fossil fuels for energy.

In 1985, about 70% of the sulphur dioxide emissions in the United States came from coal- or oil-fired electrical generating stations; in Canada, about 50% was emitted from ore smelters and about 20% from generating stations burning fossil fuels. Sulphur emissions in both countries tend to be concentrated in a relatively few locations. By contrast, the sources of nitrogen emissions are widely distributed. About 40% of nitrogen oxides come from transportation (cars, trucks, buses, trains), about 25% from thermoelectric generating stations, and the balance from other industrial, commercial, and residential combustion processes.

Figure 24.3 shows the distribution of North American sources of sulphur oxides and nitrogen oxides and the levels in the geographical areas delineated on the map. In 1980, which has served as the reference year for tracking emissions, sulphur dioxide emissions were estimated to be 4.6 million tonnes in Canada, and 24 million tonnes in the United States. Emissions of nitrogen oxides in the two countries were 1.8 million and 20 million tonnes, respectively. Figure 24.4 shows trends for sulphur dioxide emissions in eastern Canada and in Canada as a whole, along with 1994 emission control objectives for eastern Canada.

Sulphate deposition

As noted in Chapter 2, airborne acidic pollutants are often transported thousands of kilometres from their point of origin before being deposited. Because the movements of air masses and storms tend to follow systematic patterns, pollutants from particular locations are, in effect, channelled away and generally fall on the same recipient areas. In eastern North America, weather patterns generally travel from southwest to northeast. Thus, pollutants emitted from sources in the industrial heartland of the midwestern states and central Canada regularly fall on the more rural and comparatively pristine areas of the northeastern United States and southeastern Canada.

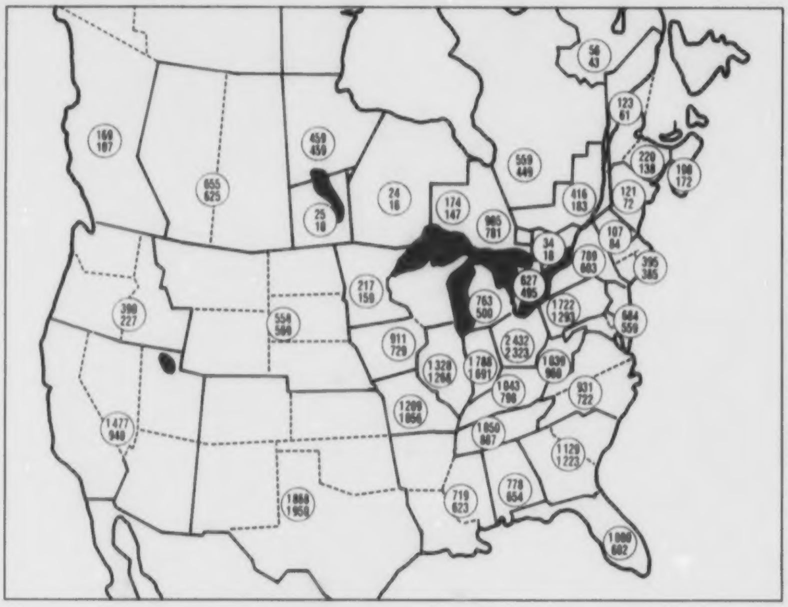
Because sulphur dioxide emissions are monitored at their source, they can be measured for both Canada and the United States on a provincial or state basis. Computer-based simulation models use emission data such as those on Figure 24.3 to approximate where the pollutants will be transported. These hypotheses are then confirmed by comparison with the actual amount of sulphate deposition recorded at weather monitoring stations across Canada and the United States. Modelling enables researchers to estimate how much of the sulphate measured at a given recording station originates in a particular region. By this method it has been estimated that about 50% of the sulphate deposited in Canada is derived from sources in the United States (RMCC 1990, part 3).

Figure 24.5 shows the annual rate of sulphate deposition across North America in 1980. It is evident that southern Ontario and southwestern Quebec received the greatest amounts. (The average pH of precipitation in central Ontario is about 4.2 [RMCC 1990, part 3].) By correlating the amount of acidic deposition in a given region with observed damages to ecosystems, it becomes possible to describe the responses that can be expected from differing levels of acidic emissions and subsequent deposition.

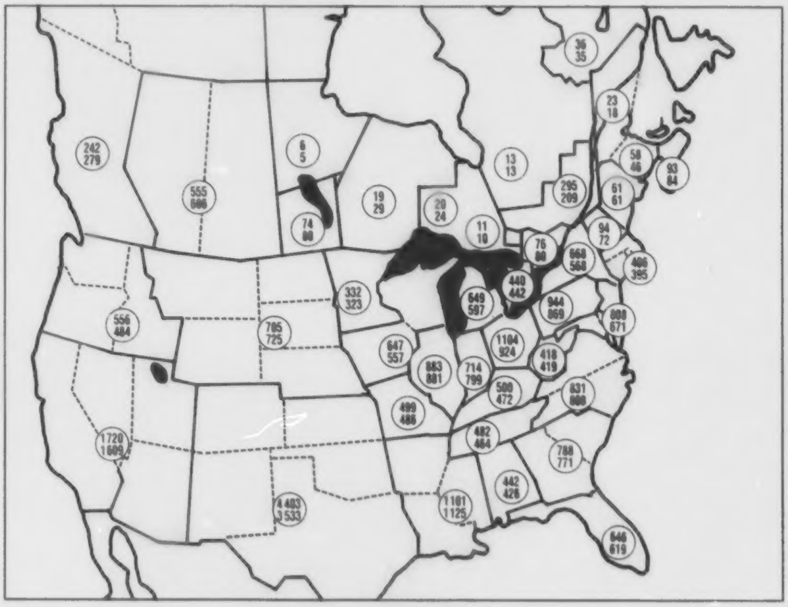
A continental network of weather stations has been monitoring acidic deposition since about 1979, long enough to indicate changes or trends that have occurred over the past decade. Sulphate deposition in precipitation,

[illegible]

Where acidic pollutants come from: principal sources of oxides of sulphur (SO_x) and oxides of nitrogen (NO_x) and the levels in each geographical area in 1980 and 1985


56 43
123 61
169 187
450 450
560 449
220 138
190 172
655 625
24 16
174 147
416 183
121 72
985 781
25 10
107 84
34 18
789 603
395 385
217 158
627 495
390 227
554 500
763 500
1722 1293
664 559
911 729
2432 2323
1328 1266
1786 1691
1639 980
1843 798
931 722
1209 1054
1477 940
1050 887
1129 1223
1868 1950
719 623
778 654
1000 602

● 1980 SO_x emissions (1,000s)
1985 SO_x emissions (1,000s)

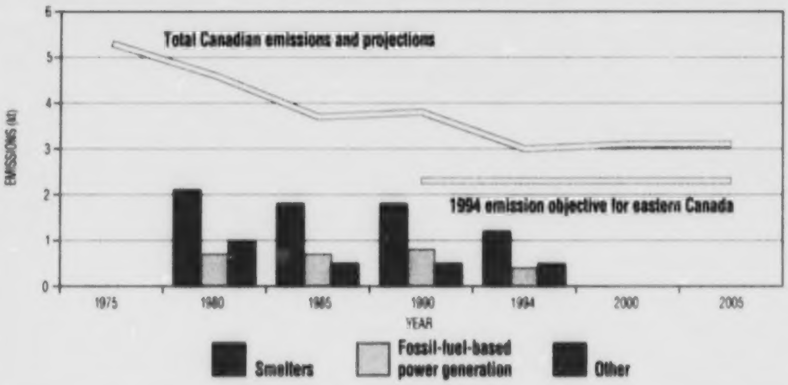

36 35
23 18
242 279
6 5
13 13
58 46
93 84
555 606
19 29
20 24
295 209
61 61
74 88
11 10
76 88
668 568
94 72
406 395
332 323
440 442
649 597
944 869
556 484
705 725
808 671
1104 924
647 557
883 881
714 799
418 419
500 472
499 486
631 606
1720 1609
482 464
788 771
4483 3533
442 426
1101 1125
646 619

● 1980 NO_x emissions (1,000s)
1985 NO_x emissions (1,000s)

Source: RMCC (1990, part 2).

FIGURE 24.4

A positive trend: actual and projected emissions of sulphur dioxide in eastern Canada, 1975–2000, by sector of origin

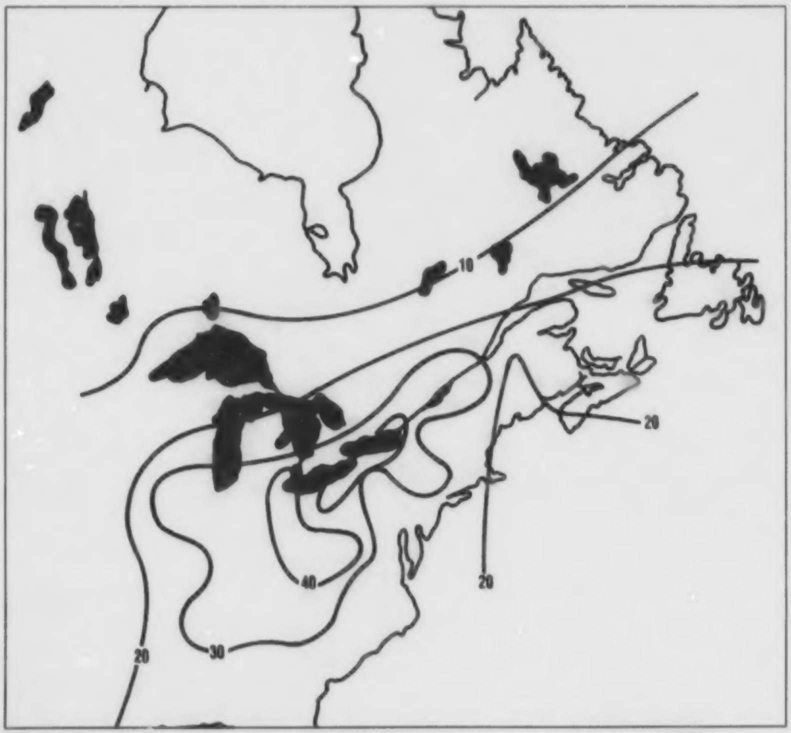


Source: RMCC (1990, part 2).

FIGURE 24.5

Where acidic deposition fell across North America in 1980

The numbers represent concentrations of acidic (sulphate) deposition expressed in kilograms of sulphate per hectare per year. The lines outline areas that accumulate more than 10, 20, 30, and 40 kg/ha in a year.



Note: Elevated levels of sulphate deposition in parts of Alberta and Saskatchewan are due to the presence of calcium sulphate in wind-blown, nonacidic soil (RMCC 1990, part 3).
Source: Barrie and Hales (1984).

though still at undesirable levels in many parts of eastern Canada, has declined at an approximately steady rate (see Fig. 24.6). When averaged over eastern North America, the decline in sulphate deposition is seen to be in nearly direct proportion to the decline in emissions. This observation supports the proposition that levels of acidic pollutants in the atmosphere can be reduced by reducing emissions.

ECOLOGICAL EFFECTS OF ACIDIC DEPOSITION

Once it enters an ecosystem, acidic pollution influences a wide variety of ecological processes. Figure 24.7 gives an idea of the complexity of the water cycle throughout terrestrial and aquatic ecosystems. The water cycle in nature is analogous to the circulation of blood in a living creature. When blood chemistry is altered beyond acceptable limits, the basic life functions of the organism are impaired. Acidification throughout the water cycle can have a similar effect on entire ecosystems, and therein lies its importance as a major threat to the health of the environment on both regional and global scales.

Compared to the slow pace of natural geophysical and evolutionary processes, the systemic changes induced by these airborne contaminants have been virtually instantaneous. Such abrupt and radical events have the potential to wreak havoc on ecosystems whose rhythm of evolution and adjustment is often measured, not in years and decades, but in centuries and millennia.

Sensitivity of ecosystems

The effects of abnormally acidic water on rocks, soils, plants, and animals combine to determine the ultimate response of ecosystems, and especially the fresh water that they contain, to acidic deposition. Rock weathering may be accelerated, soil nutrients and trace metals may be altered, plant growth may be impaired, and the ability of habitats to sustain living organisms may be diminished. The degree to which a particular area is unable to resist the damaging effects of acidic deposition is termed its sensitivity to acidification.

The sensitivity of a region or ecosystem is directly related to its capacity to neutralize or counter excess acidity. If, following an episode of acidic deposition, adverse effects are minimal and conditions return quickly to near normal, the ecosystem is not considered to be sensitive. If, on the other hand, the ecosystem suffers severe damage because it has little ability to neutralize acidic pollutants, it is deemed to be highly sensitive.

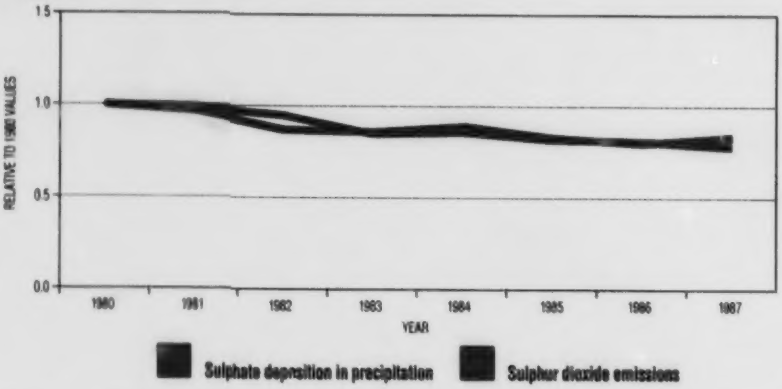
The capacity of any region to neutralize acidity is determined primarily by the characteristics of its soils and bedrock (Cowell and Lucas 1986). A model based on available information from terrain, soil, and ecological land inventories ranks Canadian landscapes in three sensitivity classes — high, moderate, and low — with regard to their potential to withstand acidic deposition (Fig. 24.8). A large proportion of the landscapes with low capacity for reducing acidity, and thus with high sensitivity, lie in the Canadian Shield. This area is dominated by granitic bedrock and thin, poorly developed soils, and it contains a large proportion of Canada's wealth of lakes and wetlands. In all, the highly sensitive category encompasses about 4 million square kilometres, about 46% of the country's surface area.

Clearly, the occurrence of high levels of acidic deposition in regions with low neutralizing capacity is most likely to seriously damage ecosystems. By comparing the areas with high levels of wet sulphate (sulphate measured in precipitation) deposition (Fig. 24.5) and the areas of high sensitivity (Fig. 24.8), it is easy to see where the two conditions coincide. It is there that there is the greatest cause for concern. In 1980, more than 10 kg/ha of sulphate was deposited over sensitive landscapes in

FIGURE 24.6

Trends in sulphur dioxide emissions and wet deposition of sulphate

Averaged over eastern North America, the decline in sulphate deposition is almost directly proportional to the decline in emissions.

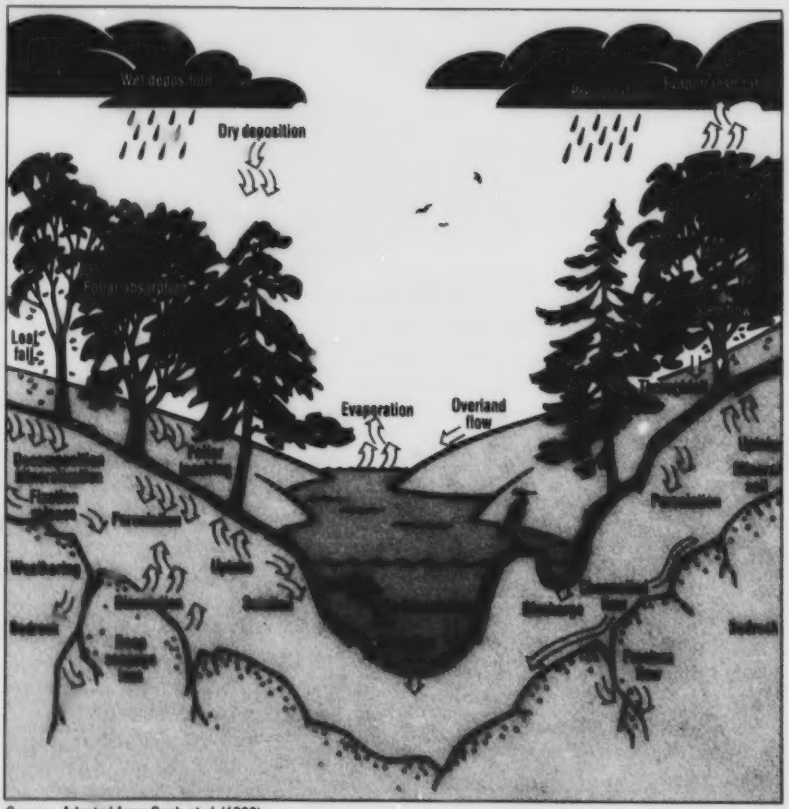


Source: RMCC (1990, part 3).

FIGURE 24.7

A simplified water cycle in terrestrial and aquatic ecosystems

On the right the figure shows the natural cycle, and on the left it shows the pathways of pollutants into the natural cycle.

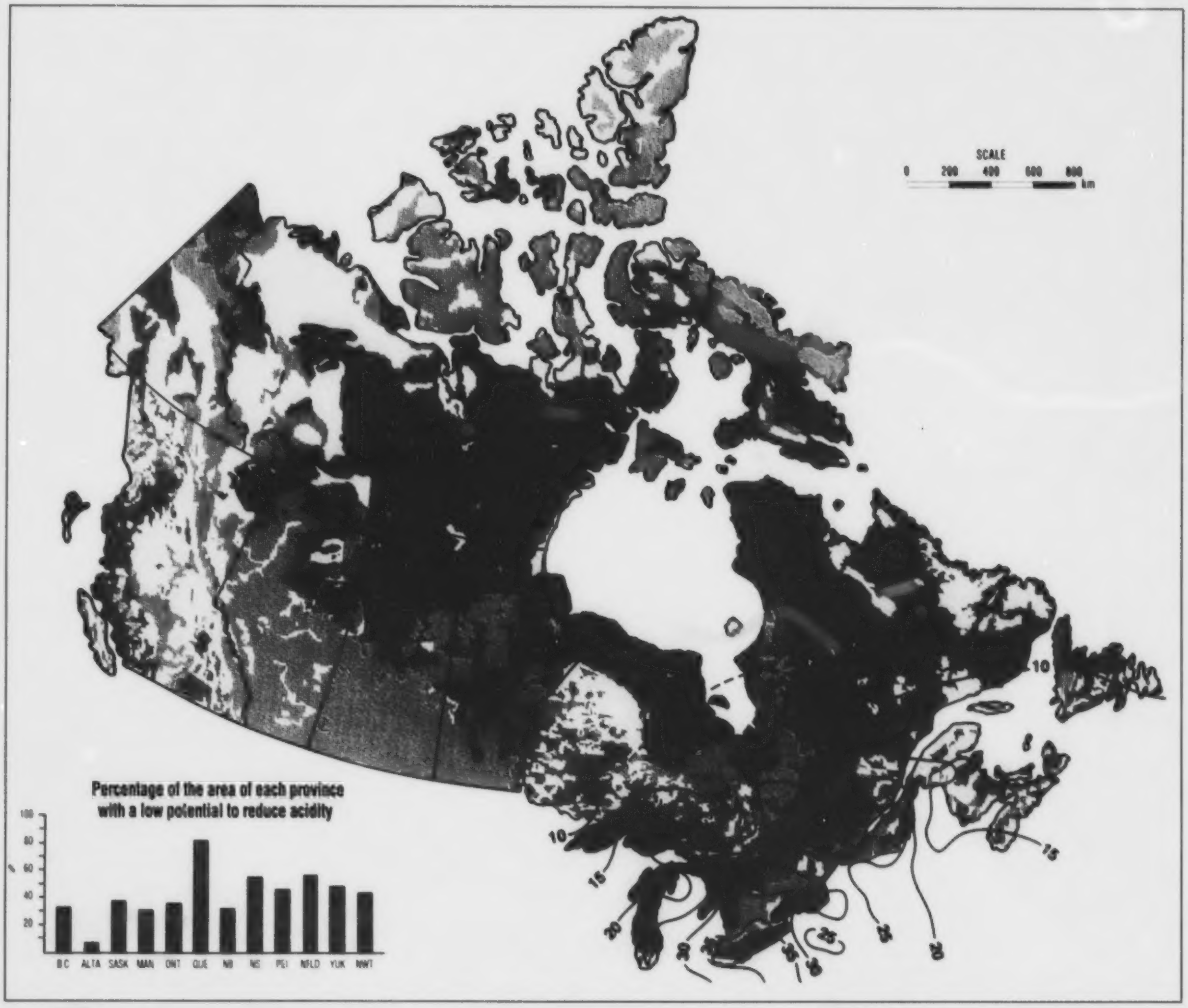


Source: Adapted from Cook *et al.* (1988).

FIGURE 24.8

Where the problem hits hardest

This is a generalized interpretation of the ability of terrestrial systems to buffer the acidity of atmospheric deposition before it reaches surface waters. Areas with low potential to reduce acidity tend to be highly sensitive to damage from acidic deposition.


SCALE
0
200
400
600
800
km
10
10
15
15
20
20
20
25
25
30
35
35
Percentage of the area of each province with a low potential to reduce acidity
%
100
80
60
40
20
BC
ALTA
SASK
MAN
ONT
QUE
NB
NS
PEI
NFLD
YUK
NWT

■ **Low: areas containing mostly noncarbonate bedrock and coarse-textured shallow soils**

■ **Unrated: dominated by peatlands**

☐ **Moderate: Areas containing mostly noncarbonate bedrock and/or shallow to deep soils**

▨ **Unrated: dominated by permanent ice and snow fields**

■ **High: Areas containing mostly carbonate bedrock and/or deep fine-textured soils**

— **Sulphate measured in precipitation in kilograms per hectare in 1980**

Source: Environment Canada (1988).

Ontario, Quebec, the Atlantic provinces, and, to a lesser extent, southwestern British Columbia. Significant, and in some cases severe, ecological responses to acidic deposition, in the form of damage to lakes, are found in these regions.

Terrestrial responses

Figure 24.7 reveals a variety of opportunities for interaction between acidic deposition and terrestrial ecosystems. In wooded areas, for example, the foliage of the upper canopy will intercept and collect some precipitation, including its acidic burden. The leaves also filter out dry particulates and gases and slow the rate at which acidic pollutants reach the ground. When such substances do enter the soil, whether in free-fall from the air or by trickling down tree trunks and plant stems, they elevate the acidity of the groundwater and alter natural soil cycles, generally diminishing the availability of soil nutrients and accelerating the process of chemically wearing away the soil. Heightened acidity also induces new reactions to which the ecosystem is not adapted. Principal among these is an increased demand for, and release of, the so-called "basic" (i.e., alkaline) elements, such as calcium and magnesium, into the water in the soil.

Initially, this leaching of basic elements away from plant roots and soil particles serves to buffer and neutralize the excess acidity. However, many Canadian soils have minimal reserves of basic elements. As the rate of leaching exceeds the availability of these buffering materials, the water remains acidic. Metals that are toxic at elevated concentrations, such as aluminum, begin to dissolve and are transported by the groundwater flow to streams and lakes. In some instances, the soil may undergo such radical modifications that it can no longer sustain certain established plant populations.

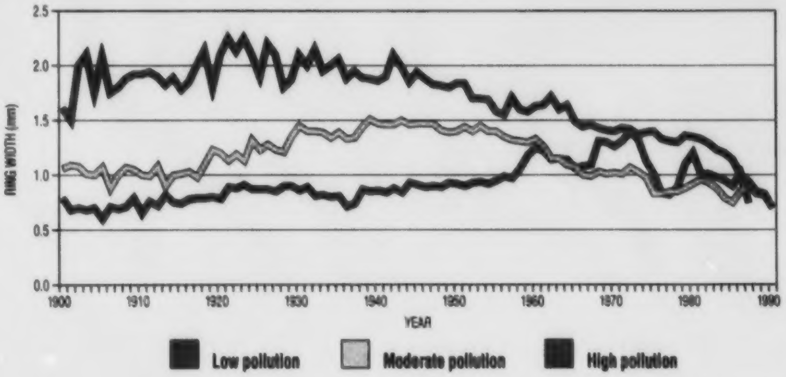
It is thought that acidic and other atmospheric pollutants may damage vegetation not only through modification of nutrients in the soil, but also through direct contact with plant tissues. Controlled experiments have shown that these substances can alter the waxy, protective surfaces of leaves and the capacity of guard cells to function. The implications of these changes are not yet well understood, but they are believed to decrease disease resistance and may also inhibit germination and reproduction of the species affected.

Plants may also be affected by indirect modifications of the ecosystem. High soil concentrations of aluminum can prevent the uptake and use of nutrients by plants. The leaching of soil nutrients and the release of toxic aluminum, as a result of acidification, may result in nutrient deficiencies or imbalances in plants. The damage is not limited to individual species of plants and animals, but in many instances extends to the biological communities in which they exist. Increased availability of aluminum in soils has been implicated as a cause of forest declines in Europe and North America (RMCC 1990, part 5).

FIGURE 24.9

Sugar maple growth in areas of high, moderate, and low levels of atmospheric pollution, 1900–90

Year-to-year fluctuations probably reflect variable climatic condition, but in the highly polluted areas the downward trend since 1960 is unmistakable.



Source: RMCC (1990, part 5).

Forests

Extensive forest declines and diebacks have occurred in Europe (Krause *et al.* 1986) and on the higher slopes of eastern mountains in the United States (Johnson *et al.* 1986). Much of the evidence points to acidic deposition as a cause of this damage.[1] In eastern Canada, 96% of the land with high capability for forestry is subject to acidic deposition in excess of 20 kg/ha per year (Lynch-Stewart *et al.* 1987). Approximately 15 million hectares of hardwood and mixed-wood forests are exposed to significant levels of sulphate and nitrate deposition (RMCC 1990, part 5). In recent years, important instances of dieback and declines in growth rate have been noted in sugar maple groves (see also Chapter 10) in parts of Canada that receive high levels of these and other air pollutants, such as ozone.

In Ontario, significant symptoms of decline are occurring throughout the range of hardwood forest, especially in northern locations. In support of this observation, Figure 24.9 shows variations in the growth rate of Ontario maple stands located in areas of high, moderate, and low pollution. The declines, most notable over the past 30 years, coincide with a period of rapidly increasing industrialization and urbanization across much of the province. A survey of more than 2 million hectares of sugar maple stands in Quebec, conducted between 1985 and 1987, revealed the following damages: 3% of the area exhibited severe damage (>25% defoliation); 47% exhibited moderate damage (11–25% defoliation); 50% showed only marginal symptoms (<10% defoliation). One disquieting aspect is that indications of decline among maples increased noticeably during the two years of the study.

White birch stands in eastern Canada may be in even more serious condition. A survey in the Bay of Fundy region in

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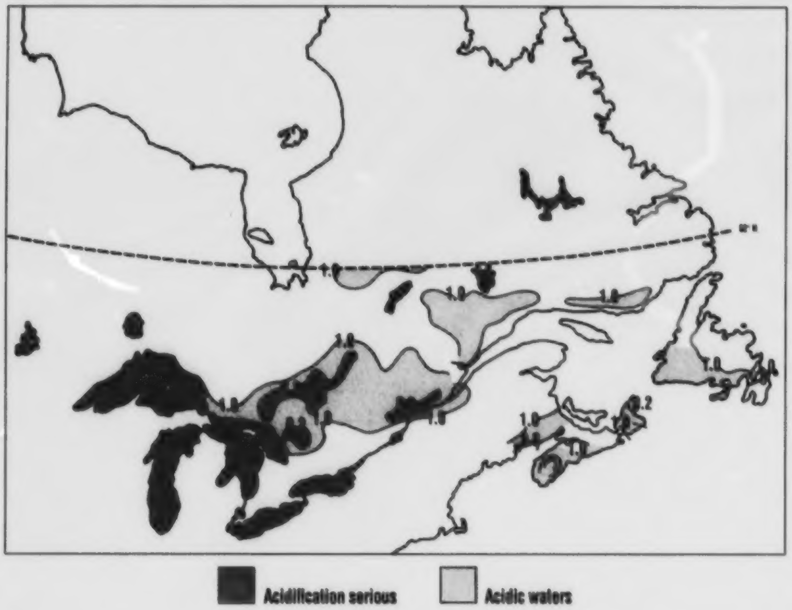
[1] In addition to acidic pollutants, Canada's forests endure the combined pressures imposed by other stresses: climatic extremes and changes, invasions by insects and diseases, and the harvesting practices of the forest industry. All of these stresses modify forest health and productivity. In view of this complex situation, it has not been possible to establish the exact role of acidification in forest decline, nor to develop critical deposition levels at which damages are believed to become important (RMCC 1990, part 5). However, the geographical coincidence of forest decline in regions of elevated acidic deposition strongly suggests that such links exist. Nitrogen oxides also contribute to the formation of ozone in the air near the Earth's surface; at low elevations, ozone may act in conjunction with acidic deposition to harm vegetation, including forest growth.

FIGURE 24.13

Acidification of surface waters in eastern Canada

Numbers represent the ratio of bicarbonate to sulphate in the lakes tested. Where the value is less than 1.0 (ratio of 1:1), the waters are experiencing serious acidification.



Source: Jeffries (1991).

1988 revealed that nearly all specimens were affected to some extent, and about 10% of the trees were already dead (RMCC 1990, part 5). Similar patterns of decline have been observed in stands of white birch on the shores of Lake Superior, another area where acid fog occurs frequently. The contribution of acidic pollutants to forest health problems is a subject of ongoing study by federal and provincial forestry departments.

Farmlands

Acidic deposition alters soil chemistry on farmlands as well as forests. The application of agricultural lime as a neutralizer has become a standard practice in many parts of eastern Canada. The precise effect on crop yields of exposure to ambient levels of acidic pollutants is unknown. Experimental work in this field is ongoing but, partly because of complex interactions with other pollutants such as ozone, it has not yet been possible to establish critical levels of acidic deposition in relation to crop damage.

Terrestrial wildlife

The effects of acid rain on terrestrial wildlife are even harder to assess. Generally, they would occur indirectly, as a result of pollution-induced alteration of habitat or food resources. Loss of forest cover, for example, could reduce available habitat for many species of birds. European studies have indicated that alteration of the cycle of calcium nutrients in soils and waters causes dietary deficiencies and may result in eggshell thinning and poor reproductive success. In Canada, evidence suggests that lichens and other plants take up and concentrate toxic metals, which may in turn accumulate in the livers of large ungulates such as caribou and moose. The amount of cadmium in moose livers has been found to be high enough that humans should avoid or limit consumption of this organ (RMCC 1990, part 5).

Aquatic responses

Canada has a wealth of fresh water. Lakes, streams, and wetlands cover about 7.6% of the country's surface area, and the volume of groundwater is many times greater than the volume of surface water. Recently, a satellite study of water bodies (Hélie and Wickware 1990) was conducted for the region of Canada that is most affected by acidic pollution, that is, the area east of the Manitoba–Ontario border and south of 52° north latitude. In this region more than 775 000 water bodies larger than 0.18 ha were identified.[2]

The task of gathering and evaluating data on all these lakes, ponds, wetlands, streams, and rivers is immense: at present, chemical analyses are available for only about 1% of the total. Even though some of the data were collected as early as the 1950s, systematic surveys have been conducted only during the last decade. Fortunately, this limited sampling base offers a reasonably good representation of the chemistry of the entire water resource, although there is a possibility that acidic and highly sensitive waters may be underrepresented.

Water chemistry is determined by the interaction of precipitation with the geological and biological conditions that exist over a given region. Surface waters that have been derived from unpolluted precipitation, and that flow through weathered soils and rocks before reaching streams and lakes, will contain dissolved basic elements, like calcium and magnesium, along with a chemical equilibrium of bicarbonate (HCO_3).[3] The concentration of these chemicals is determined largely by the geological properties of the watershed.

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[2] Within that total, 54% of the lakes covered less than 1 ha. Although such tiny lakes contain a relatively small proportion of the total supply of surface fresh water, they provide essential habitat for waterfowl and aquatic organisms (McNicol *et al.* 1987). Any influence that may disturb the balance of these vital ecosystems must be viewed with concern.

[3] For a more detailed discussion of water chemistry, readers should consult one of the standard texts, such as Stumm and Morgan (1970).

Waters low in dissolved minerals are termed "soft," whereas those with high concentrations are termed "hard."

Most of the unpolluted waters in eastern Canada are naturally very soft (LRTAP Working Group 1989) due to the bedrock and soil characteristics of the Canadian Shield. The same characteristics that produce soft waters also define areas that are sensitive to acidic deposition. Such waters, unless otherwise polluted, will have a near-neutral acidity, ranging between pH 6 and somewhat greater than pH 7, and will contain only trace amounts of sulphate or nitrate (RMCC 1990, part 4).

When pollutants containing sulphuric and nitric acids are introduced into soft waters, the acids are first neutralized or buffered by the bicarbonate and, to some extent, by the release of other elements, including aluminum. The evidence of such early acidification is most easily detected by the loss of bicarbonate and the appearance of sulphate in the water. At this stage, any nitrate that is deposited is usually assimilated as a nutrient by plants. It contributes directly to acidification of the water only when vegetation and other aquatic organisms cannot assimilate all that is deposited. When all the available bicarbonate in the water body has been exhausted, the waters become significantly acidic, with a pH of 5.0 or lower. Researchers can measure the degree to which acidification has taken place in a lake by determining the relative amounts of bicarbonate and sulphate in samples of its water.

To determine how widespread the acidification of waters in southeastern Canada might be, more than 8 500 lakes have been surveyed and analyzed for their chemical content (RMCC 1990, part 4). Figure 24.10 summarizes the geographical distribution of waters according to the relative amounts of bicarbonate and sulphate. In areas where the ratio of bicarbonate to sulphate is less than one part bicarbonate to one part sulphate (shown on the figure as 1.0), the waters are experiencing serious acidification. If the ratio has fallen to 1:5 (expressed as 0.2) or lower, it would be expected that many acidic water bodies with a pH below 5 would be found. As the map indicates, large portions of Ontario, Quebec, and the Atlantic provinces fall into these classes.

In addition to the long-term process of acidification, short-term events can have severe consequences for small bodies of water. In much of Canada, a large proportion of the total annual precipitation is deposited as snowfall, or in severe rainstorms. Sudden spring snowmelts and heavy storm runoffs have the potential to introduce large quantities of acidic pollutants into the surface water system in a very short time, introducing massive pulses of increased acidity to local streams and lakes. On occasion, these temporary pulses or "acid shocks" have killed large numbers of fish (Marmorek *et al.* 1987) before the sudden input of acidity could be buffered. Because acidity in this form does not have time to be assimilated gradually into the environment, it is of particular concern, even in areas where long-term acidification has not yet reached levels that would normally be considered serious.

Aquatic organisms

Changes in the flora and fauna of aquatic ecosystems are often the first and most immediate indicators of acidification in the lakes of eastern Canada. The interactions between living organisms and the chemistry of their water habitats are extremely complex. If a species or group of species increases or declines in number in response to acidification, then the ecosystem of the entire water body is likely to be affected. Reactions of organisms to stresses such as acidification have been termed "dose–response reactions" (i.e., a certain dose of an acidifying pollutant induces a certain reaction).

By causing direct changes in a single component of the food web of an ecosystem, acidification can indirectly modify predator–prey relationships throughout the entire system. These indirect effects make accurate assessment of biological damage difficult, as it is necessary to understand which effects are caused directly by acidic pollution to draw dependable conclusions. By the time that a major biological response, such as the loss of a given fish stock, has become evident, serious damage may already have occurred in the aquatic ecosystem.

Knowledge relating biological responses to habitat acidification has been obtained from small-scale experiments in laboratories, from whole ecosystem experiments in which entire lakes are artificially acidified, and from extensive field surveys and monitoring. By combining these sources of information, quite a precise understanding of the effects of acidification on aquatic organisms has been obtained (RMCC 1990, part 4).

At first, the effects may be almost imperceptible, but as acidity increases, more and more species of plants and animals decline or disappear (see Fig. 24.1). Crustaceans, insects, and some algal and zooplankton species begin to disappear as the pH approaches 6.0, but most fish are not, as yet, affected directly. As acidity increases from pH 6.0 to pH 5.0, major changes in the makeup of the plankton community occur, and progressive losses of fish populations are likely, with the more highly valued species being generally the least tolerant of acidity. Fish declines often begin with reproductive failure, leaving a diminishing stock of aging individuals; when these fish die, their disappearance gives the impression of a sudden disaster, although the sequence of events leading to it may in fact have begun long before. At this stage of pH decline, less desirable species of mosses and plankton may begin to invade. When the pH falls below 5.0, the water is largely devoid of fish, the bottom is covered with undecayed material, and the nearshore areas may be dominated by mosses. The lake, once rich in species, has gradually become an impoverished and unhealthy ecosystem.

Although most amphibians, such as frogs and salamanders, spend the greater part of their life cycle on land, they depend heavily on temporary ponds for breeding. These small, ephemeral water bodies are highly vulnerable to the "acid shock" events associated with storms and snowmelt. In several studies, reproduction of amphibians has been shown to be seriously restricted when the acidity of their breeding habitat increases to a pH value of less than 5.0 (RMCC 1990, part 4).

To date, water birds have not been shown to be directly affected by acidification. However, if acidification of their habitat should diminish the supply of fish, invertebrates, or plants on which they feed or induce elevated levels of toxic metals in the food supply, they may suffer the consequences. Invertebrates that normally supply calcium to egg-laying females and to their growing chicks are among the first species to disappear when lakes acidify. As these food sources are reduced or eliminated, the quality of habitat declines and the reproductive success of the birds is affected. Field studies have demonstrated that the Common Loon is able to raise fewer chicks, or none at all, on acidic lakes where fish populations have been reduced (Alvo *et al.* 1988; Wayland and McNicol 1990). On the other hand, there are some isolated cases in which food supplies for birds increase when competing species are removed. The Common Goldeneye, a species of duck that nests by lakes and rivers in forested terrain, can better exploit insects as food when competition from fish is eliminated. Such variations make the collective influences of acidification on bird populations difficult to quantify. Generally, however, acidification remains a continuing threat to species of waterfowl that rely on a healthy aquatic ecosystem for breeding and for rearing young, in thousands of lakes across southeastern Canada (RMCC 1990, part 4).

Human health responses

Acids in rain or snow have not been observed in concentrations that would pose a direct risk to humans. However, people do inhale airborne acidic pollutants in particulate or gaseous forms. There are indications that this exposure to oxides of sulphur and nitrogen may lead to irritation of the respiratory tract and subsequently to impaired lung function and aggravation of respiratory ailments such as bronchitis and asthma.

Humans may also be affected indirectly through exposure to increased levels of toxic metals in drinking water and food. As noted previously, increased levels of toxic metals result from the deposition of acidic pollutants into water sources, increased leaching of metals from soils and lake sediments, and increased corrosion of water pipes.

Evidence for linkages between acidic pollution and human health has been derived from epidemiologic studies of exposed human populations, from human volunteer studies, and from animal experiments (RMCC 1990, part 6). For instance, when air pollution levels in southwestern Ontario were compared with hospital admissions in the same area, positive associations were found between respiratory illness and elevated levels of sulphate, ozone, and temperature (Bates and Sizto 1989). Girls attending a summer camp in southern Ontario showed signs of diminished lung function that were correlated with episodes of acidic air pollution.

In another study, the lung function of children aged 7–12 was tested in Tillsonburg, Ontario, an area of heavy acidic pollution, and Portage la Prairie, Manitoba, where airborne acidic pollution is not severe. Lung capacity was diminished by about 2% in the more heavily polluted community (Stern *et al.* 1989). In a subsequent cross-sectional study of 10 towns in Canada, a similar reduction of about 2% in lung function was observed in populations of towns with higher air pollution levels. The difference appears to be due to acidic sulphate, although similar reactions have been known to occur in response to elevated levels of ozone.

Like other animals, humans can be affected by the entry of pollutants at other points in the food chain. For example, elevated levels of mercury, toxic to humans when consumed, have been found in fish taken from acidified waters. The mercury may be deposited by direct atmospheric transport or may have been released from local environmental sources by the acidification of the waters (Meger 1986).

Aluminum that is leached from soils by acidification and thereafter appears in increased concentrations in water and foods has been implicated by some researchers as having an association with Alzheimer's disease (Jackson and Huang 1983). However, other recent studies reported by Foncin in 1987 have found "...no environmental influence whatsoever on the incidence of the disease [Alzheimer's]." Thus, although the association is cause for continued concern, more research will be required to establish whether it is an indirect effect of acidification.

Although it has been well established that an increased concentration of free aluminum is associated with acidification, elevated levels of other metals have also been observed in drinking water, apparently resulting from the corrosive effect of acidified water on plumbing systems (Meranger and Kahn 1983). Levels of cadmium and lead, both of which are highly toxic, may be higher than acceptable if water from acidified sources stands in pipes for several hours. Allowing the tap to run to flush the plumbing before using the water for drinking or cooking is an effective way of avoiding health risks in such cases. In urban water systems, the problem of elevated metal concentrations is usually addressed by adjusting the pH of water at the municipal water treatment facility. In some rural or cottage settings, where water may be drawn directly from acidified sources, correcting the problem depends on the individual's own efforts. It may be necessary to install adequate filtering devices or, in cases of contamination from the plumbing, to flush the water supply system, to remove built-up contaminants.

SOCIOECONOMIC CONSEQUENCES OF ACIDIFICATION

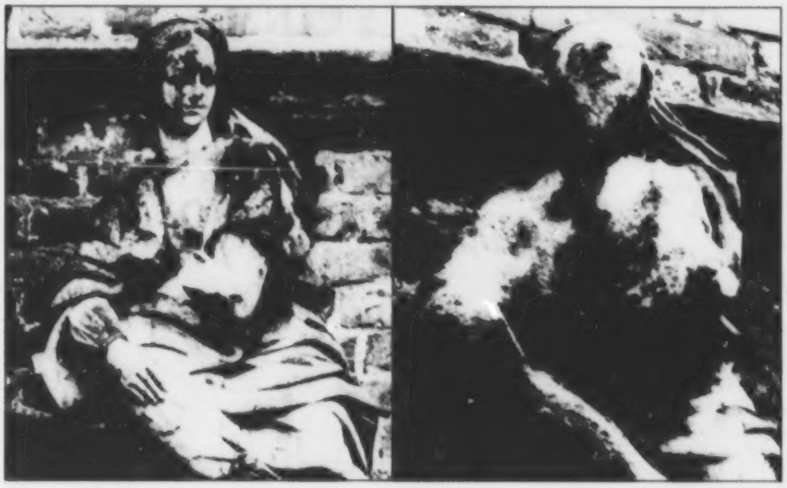
Of all of the ecological effects of acidic deposition considered in the preceding section, the best understood relationships are with surface waters. Existing knowledge permits scientists to predict the consequences of specific levels of pollution on surface water biota, and this has been done for fish populations. To date, most researchers have calculated social and economic costs of acidic deposition using these predictions of damage to fish populations. The effects of acidification in other areas, such as agriculture, forestry, and human health, are less direct, although the evidence of a link is strong. Studies are continuing that will lead to more precise measurements of socioeconomic costs due to the effects of acidic deposition on these resources. The social and economic costs are undoubtedly great in these areas as well and provide additional justification for corrective measures, such as emission controls, even in the absence of comprehensive cause-and-effect linkages.

Although damage to natural ecosystems (and associated resource industries) is the chief threat of "acid rain," other values, including symbolic values, are also at risk. The damage that acidic deposition inflicts on maple forests is also an assault on the maple leaf, the national emblem of Canada. The disappearance of the Common Loon from acidified lakes represents an impoverishment of the Canadian wilderness experience, even for urban dwellers who may never have heard its eerie call. The corrosion of heritage buildings, structures, and monuments represents an erosion of cultural identity that may surpass in importance the monetary cost of repair or replacement. And the toll that acidic pollution exacts on human beings is not restricted to a decline in physical well-being, but includes the cost to community and individual morale of knowing that air, food, and water everywhere are affected and that, even in the wilderness, some food may be hazardous. The damage to the well-being of people who live on remote wilderness lakes and depend heavily on healthy fish populations for subsistence and for income is particularly grave.

FIGURE 24.11

Corrosion of a nation's heritage

Limestone and sandstone are especially vulnerable to the effects of acidic pollution. This German ornament figure, made of sandstone, is shown in 1908 (left) and in 1969 (right).



Source: Persson (1982).

Effects of acidic deposition on buildings, monuments, and materials

All materials used in artificial structures are subject to deterioration from normal weathering. However, as illustrated in Figure 24.11, deterioration has accelerated drastically since the advent of industrial pollution (Amorosa and Fassina 1983). Damage is now significant at many Canadian heritage sites, among them the federal Parliament Buildings, where even the bronze sculpture of "Canada" shows signs of serious erosion and pitting (Weaver 1985, 1987).

The National Research Council (Gibbons 1970) provided early evidence that "corrosivity" levels were highly correlated with levels of sulphur-based pollutants. Corrosion is significantly influenced by the direction or aspect of exposure relative to wind and weather, and by other factors such as frequency and duration of wetting. However, sulphur dioxides have specifically been linked with the rates of deterioration of building materials (Kucera 1983). Research efforts to establish quantitative measurements of such relationships are nearing the reporting stage in both the United States and Britain (National Acid Precipitation Assessment Program 1990; Building Research Establishment 1990).

Modern building materials have been developed to retard such deterioration. However, a great many of the historic buildings and statues that make up our cultural heritage are built of stone, brick, and masonry. The reactions of sulphur-based solutions on the surfaces and in the pore structures of these materials produce faster rates of erosion, chipping, fracture, and discolouration. Although a general lack of long-term measurements has hindered development of precise relationships, it is now well known that acidic pollutants are the cause of a rapid increase in the decay of historic structures.

Extensive repair and restoration work has been required to reverse the advanced deterioration of many of Canada's heritage buildings. These include the Art Gallery of Nova Scotia (formerly the Federal Building), the Provincial Court in Quebec City, the Bell Telephone Exchange in Montreal, St. James' Cathedral in Toronto, St. Paul's Church in Hamilton, and, to a lesser extent, the Bank of Montreal in Winnipeg (M. Weaver, conservation consultant, personal communication).

Economic costs of acidification

Traditionally, economic losses are expressed in dollar costs and are associated with cases where such values can be assigned. Although costs can be attached to some of the effects that have been discussed thus far, many of them defy this sort of interpretation. What is the real value of fish in a lake so remote that they may never encounter an angler's lure? How do we put a price on the pleasure of listening to birdsong or wandering through a healthy forest?

One of the most evident and measurable losses due to acidification is the damage to the recreational fishery. Although the methodology of evaluation remains imprecise, in 1985 an estimated 3 million resident Canadians and 680 000 nonresidents engaged in more than 57 million angler-days of recreational fishing activity in eastern Canada. On the basis of present emission control actions, analysts have forecast that an annual increase of 5.2 million angler-days will result from improved fishing quality during the period 1986–2015. If each angler-day is valued at $73 in direct expenditures and related investment, the direct annual increase in angler spending that is projected as a result of emission/deposition controls would be about $380 million when averaged over the 30-year period (DPA Group Inc. 1987).

To take another example, an accurate estimate of the cost of acidification to the Canadian forest industry has yet to be determined. Effects that have been documented are believed to result from multiple stressors. In the absence of precisely understood relationships, a hypothetical economic value for loss of forest growth has been calculated, assuming an average reduction in growth of 5% for forest regions that are subjected to acidic deposition (Crocker and Forster 1986). Such a loss in growth, if continued on a yearly basis and converted into allowable timber harvest, would represent a potential annual economic loss of about $197 million. Nontimber losses, such as the loss of maple sugar production, the disruption of forest-based recreation, or the loss of wildlife habitat, have not been estimated. In 1987, the Canadian forest industry contributed $20 billion to the Canadian economy. In view of this, even a decline of 1 or 2% in yield on an annual basis would represent a serious threat to industry efforts to increase production (RMCC 1990, part 5).

As indicated previously, damage to heritage structures must to a large degree be assessed in terms of cultural values. We cannot easily assign a dollar value to an ancestral grave marker, to native petroglyphs on some unexplored cliff face, or to the carved stone facade of the Parliament Buildings. However, the additional annual maintenance costs for the exterior of buildings (e.g., painting) across Canada as a result of damage from acidic deposition has been estimated at about $830 million (Weaver 1985). This figure does not include damages to underlying structures, which may well be greater, albeit more difficult to assess.

The health care costs resulting from exposure to acidic pollutants cannot be separated from the overall effects of air pollution. It has been found that impairments of lung function are greater in relation to sulphate exposures than to other measures of air pollution. The 2% impairment in lung function that was observed in school children under increased levels of pollution exposure may accumulate over a lifetime, producing an age-related decline of up to 20% (Berkey *et al.* 1986). Hospital admissions for respiratory diseases have been linked to increased exposure to air pollutants (Bates and Sizto 1989). Although the overall economic impact of these health effects has not been determined, the combined effect of direct medical expenses and indirect losses of work time and productivity must be considerable.

Economic costs of emission controls

Although the proposed control strategy includes reduction of transboundary flow of sulphur dioxide from the United States, only the costs for implementing Canadian controls are considered here. The costs of reducing and controlling sulphur emissions have been evaluated for two categories: the smelting of sulphur-bearing ores, and the burning of sulphur-bearing fossil fuels in thermoelectric generating stations. The largest target for emission reduction from thermoelectric power generation has been imposed to Ontario Hydro, although some reductions have also been imposed on the power commissions of Nova Scotia and New Brunswick.

For Ontario Hydro, the goal is to achieve a reduction from the 1980 level of 462 000 t of acid gas emissions (sulphur and nitrogen oxides) to a 1994 level of 215 000 t. This will cost an estimated $2.46 billion. At the level of the consumer, this will result in an average increase in electric utility rates of about 2.8% per year between 1990 and the turn of the century. If some portion of the technology required to control emissions were to be developed and acquired within Canada, a portion of these direct costs could be recovered through other sectors of the economy. Such indirect benefits have not been assessed (Ontario Hydro 1989). Costs to other provincial utilities to achieve their assigned emission reductions have been estimated as follows: New Brunswick Hydro Electric Power Commission — $210 million; Nova Scotia Electric Power Commission — $590 million.

Targets for the reduction of emissions from the smelting of sulphurous ores have been set for five major companies operating in Manitoba, Ontario, and Quebec. Technical plans to achieve the assigned reductions differ among the specific operations (see Box 24.1). The estimated capital cost of smelter modifications and associated expenditures is $827 million. On the credit side, greater operational efficiencies would be achieved, and this, along with recovery of sulphuric acid valued at $2 million per year, would permit a payback of the capital investment over a number of years. Some adjustment of labour force would also be expected (Falconbridge Ltd. 1988; Inco Ltd. 1988).

BOX 24.1

Signs of progress

Once the fundamental decision to reduce acidic emissions was accepted, some of Canada's largest producers of sulphur dioxide and nitrogen oxides showed commendable speed and effectiveness in implementing control measures.

Ontario Hydro's coal-fired generating stations currently emit about 15% of all acid gas emissions in Ontario, or 1% of the North American total. During the 1970s, the demand for electricity increased. So did the emission of acidic gases from the utility's plants, reaching a peak of 531 000 t in 1982. That was the year Ontario started regulating annual emission limits. By 1990, Ontario Hydro had cut its annual total emissions to 245 000 t, a drop of more than 50% in eight years. Continued progress is assured by the fact that the annual limit set by the province for the years 1990–93 is 280 000 t, and from 1994 on is 215 000 t.

Ontario Hydro describes its abatement strategy as a portfolio of demand-side and supply-side measures that allows the utility to implement the most appropriate measures where and when needed (D.B. Curtis, Ontario Hydro, personal communication). On the demand side, it has used information programs, incentives to improve efficiency, and other measures to influence the amount and timing of consumer demands for electricity. On the supply side, it has reduced its use of coal as an energy source, in favour of hydraulic and nuclear generating technologies. In existing coal-fired facilities, Ontario Hydro is using low-sulphur fuels and is committed to installing emission control equipment. It is also examining methods and technologies that will further diminish production of sulphur dioxide and nitrogen oxides.

Apart from thermoelectric power generation, the other major industrial process that produces acidic air pollution is the smelting of metals. Two of Canada's largest mining and metallurgical companies, Inco Limited and Noranda Inc., have vastly improved their pollution records in recent years.

The acknowledged giant among industrial producers of sulphur dioxide emissions has long been Inco Limited. In 1969, Inco's plant at Copper Cliff, near Sudbury, Ontario, was releasing sulphur dioxide into the atmosphere at a rate of 5 500 t/day, or about 2 million tonnes annually. Since then, a combination of positive company initiatives and government emission control regulations has reduced annual emissions to 685 000 t.

To meet future regulatory limits, Inco has developed programs that will lower its sulphur dioxide emissions to 265 000 t annually by 1994 and is studying the possibility of reducing emissions further in the years ahead (E. Kustan, Inco, personal communication).

In 1980, the Noranda Minerals copper smelter at Rouyn-Noranda, Quebec, was emitting just over 550 000 t of sulphur dioxide annually. In 1987, Noranda, the federal government, and the Province of Quebec signed an agreement whereby Noranda would reduce its sulphur dioxide emissions by 50% by 1990. Extraction of sulphuric acid, new smelting technologies, and the replacement of a portion of the high-sulphur ore concentrates by recycled metals have all contributed to achieving this goal. Noranda has now made a further commitment to a 90% reduction, by the year 2000, of sulphur dioxide emissions from the 1980 levels while conserving its established smelting capacity (D. Coffin, Noranda, personal communication).

RESOLVING THE ACIDIFICATION ISSUE

Public awareness and support

Since 1978, the federal and provincial governments have funded research aimed at improving both the knowledge and the management of environmental acidification. The largest research initiatives have been the Acid Precipitation in Ontario Study (Ontario Ministry of the Environment 1979) and the federal Long-Range Transport of Air Pollutants Program (1978). These and other programs set investigations in motion and supported the continuation and expansion of university-based research. The objectives of the federal LRTAP program were a) to determine the state of the environmental conditions in eastern Canada prior to the incidence of coal-burning emissions in North America; and b) to develop a clear understanding of the occurrence and effects of long-range transport of airborne pollutants within and into Canada, including geographical extent, severity, and socioeconomic costs.

During this period of rapid program development, the public awareness of "acid rain" was heightened by open seminars, published brochures, scientific articles, press releases, and the emergence of public advocacy groups (Brydges 1987). The Sierra Club of Ontario, in cooperation with other public interest groups, sponsored an in-depth and well-publicized "Action Seminar on Acid Precipitation" (1979). Also during this period, discussions were begun with the United States, leading to establishment of the United States – Canada Research and Consultation Group on LRTAP. The first meeting of this international group was held in July 1978, and the first international report was jointly issued in October 1979 (U.S.–Canada Research Consultation Group 1979).

Through the interaction of scientists, governments, and the public, interdisciplinary programs were developed involving various government departments and levels of government in both Canada and the United States. The stage was set to obtain the information needed to develop policies on how to manage the acidic deposition issue and to address this problem on a continental scale.

Formulating management policy

On August 5, 1980, the governments of Canada and the United States signed a memorandum of intent "to develop a bilateral agreement on transboundary air pollution, including the already serious problem of acid rain." Bilateral working groups were established to prepare a scientific foundation for such an agreement. Drawing on available information, the working groups provided comprehensive reports on all aspects of this particular pollution issue, from emission sources, atmospheric transport, and deposition to environmental and human health effects and socioeconomic factors.

The information was sufficient to establish that vast regions of North America were sensitive to acidification, and that transport and deposition of acidic pollutants were occurring over many of these same sensitive regions. Sulphur dioxide was established as the primary acidifying agent, although nitrogen oxides were thought to reach levels of concern in some situations. However, it was not possible to demonstrate reliable causal relationships for all of the resources of concern in the affected regions, to predict specific environmental effects for given levels of sulphur deposition. Only in the case of water resources were the relationships decisive, and they were the ones used to develop environmental criteria for emission control policies. United States officials were not in full agreement even with regard to water (U.S.–Canada 1983). They felt that the limited amount of information then available restricted the confidence with which any real relationship could be assumed. However, in Canada, management actions were proposed on the assumption that later corrections would be possible as more information became available.

Using the best available dose–response information, a "target loading" for sulphate was proposed in the bilateral report (U.S.–Canada 1983). A target loading for sulphate of 15–20 kg/ha per year (this being measured as wet sulphate) would serve to maintain the pH of surface waters at a level greater than 5.3 on an annual average basis. It was recognized that this loading would only protect waters that have at least a moderate[4] capability for neutralizing acid. The "target loading" concept was not founded on a premise that all damage could be avoided. Rather, it recognized that some ecosystem damage would occur but allowed leeway to develop at least a partial control strategy, while scientists accumulated more and better information. Eventually a more inclusive and scientifically reliable target loading value could be tabled for consideration.

The confidence demonstrated in the information that was available in 1983 was insufficient to convince decision-makers in the United States. Research and monitoring programs continued in both countries. The most current assessment reports of those programs are now available, and early drafts have been reviewed in the preparation of this chapter (RMCC 1990). New information has led to increased confidence in the dose–response simulation models and in their predictive capabilities.

Control strategies

In devising control strategies, one of the first tasks has been to identify ways of reducing damage to an acceptable level. Defining acceptability in this context has been a challenge, depending as much on economic and technical factors as on environmental concerns. Three control and mitigation options have received particular consideration:

1. reduction of acidic deposition by controlling emissions of the acidifying pollutants;
2. decreasing sensitivity to acidification by adding basic materials to ecosystems (i.e., liming);
3. reduction of biological damage by introducing acid-resistant species of flora and fauna.

The second option has been exercised extensively in Sweden (Persson 1982) and has been employed in Canada on an experimental basis (RMCC 1990, part 4). This form of mitigation was rejected as being neither technically feasible nor a permanent solution to the issue. With respect to the third option, more resistant species are available only in a few cases. Reducing acidification through emission controls has therefore been judged to be the most viable strategy (U.S.–Canada 1983).

Implementation of an emission control strategy required that a target level of pollution be specified as the objective of the plan. This level, or "target loading," was based on a realistic assessment of technical feasibility and economic and political costs, as well as environmental damages. In contrast, a "critical loading" has been defined as "the highest load that will not cause chemical changes leading to long-term harmful effects on the most sensitive ecological systems" (Nilsson 1986). A "target loading" policy objective will, from practical necessity, often be less stringent than the "critical loading." Some possibility of environmental damage will often be allowed. While recognizing that the most sensitive ecosystems would not be protected, the Canadian Council of Resource and Environment Ministers (1983) established 20 kg/ha per year as the target loading for the Canadian sulphur dioxide control strategy.

Once this objective was established, existing knowledge of atmospheric transport processes was applied to estimate the amount of emission reduction that would be required. The levels of acidic sulphate that were deposited in 1980 (as high as 40 kg/ha at some sites

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[4] Base cation concentration greater than 200 μeq/L.

[Fig. 24.5]) were accepted as the reference point for determining control measures. Hence, the emission control strategy proposed that a 50% reduction in sulphur dioxide emissions would be needed to reach the desired target loading. Because roughly half the sulphate deposition recorded in 1980 was believed to originate from emissions in the United States, achieving a cooperative agreement with the United States would be an integral part of the overall control strategy. A reduction in the Canadian emissions alone could not achieve the deposition objective.

Federal–provincial negotiations were undertaken through the Canadian Council of Resource and Environment Ministers (CCREM). In February 1985, agreement was reached on the allocation of emission-reduction targets to each of the seven provinces from Manitoba eastward (Canadian Council of Resource and Environment Ministers 1985). Figure 24.4 depicts the progress and plans to reduce total emissions of sulphate in eastern Canada from a legislated limit of 4 500 kt in 1980 to 2 300 kt by 1994. The figure also shows the proportion of emission reduction assigned to smelters, fossil-fuel-powered electrical generating stations, and other sources. It should be noted that the actual emissions in eastern Canada in 1980 were only about 3 800 kt, as a result of early control efforts and existing market factors.

In the United States, amendments to the *Clean Air Act*, adopted in November 1990, form the legislative basis for control of sulphur and nitrogen oxide emissions. During Phase I, to be completed by 1995, emission limits for specific electric power generation stations will result in a total reduction of 5 million tons (4.5 million tonnes) in the annual emission of sulphur dioxide. During Phase II, to be completed by 2000, an additional 5-million-ton reduction in the annual sulphur dioxide emissions will be assigned. Allowable limits on the emission of nitrogen oxides are to be established by May 1991 (U.S. Clean Air Act Amendments 1990).

When these reductions in emissions are achieved in the United States in addition to proposed reductions in Canada, models of known transport–deposition patterns indicate that sulphate deposition will be below the 20 kg/ha per year objective over all of eastern Canada (Environment Canada 1990). Although this reduction will substantially reduce the harmful effects of acidic precipitation, results of a recent study (Long-Range Transport of Air Pollutants Program 1990) indicate that various components of ecosystems, especially sensitive aquatic organisms, will still be at some risk (RMCC 1990, part 4).

For each province to meet its emission control objectives, it will have to cooperate closely with industry. Industries have been assigned quotas, and they have filed plans detailing how and when they will cut their emissions (Algoma Steel Co. Ltd. 1988; Falconbridge Ltd. 1988; Inco Ltd. 1988; Ontario Hydro 1989). These industries have drafted estimates of the social and economic costs of the planned modifications. In some cases, federal or provincial governments will provide financial assistance. As Figure 24.4 shows, as of 1990, emissions had already been reduced. Relative to reaching the 1994 emission target, about 40 % of the reductions have been achieved.

International cooperation

The international scope of the acidic precipitation issue has long been a concern of Canadian planners. Canadians and Americans jointly published measurements of the chemistry of precipitation obtained as early as 1972 (International Joint Commission 1982), and Canada has been part of a global monitoring network, the World Meteorological Organization's Precipitation Network (World Meteorological Organization 1971), since 1972, with 10 stations in operation nationwide at that time.

Because of the way the wind blows, Canada's most important international cooperation on this issue is with the United States. Although the U.S.–Canada Memorandum of Intent did not achieve immediate agreement for the control of emissions in the United States, extensive scientific cooperation has provided information for the control strategies that are now being instituted. An independent analysis of the Canadian concern about acidification, commissioned by the U.S. Environmental Protection Agency, has reached conclusions highly supportive of the Canadian position (Cook *et al.* 1988).

On a wider international stage, Canada has maintained contact with the efforts of other countries through the United Nations. In 1979, Canada joined other nations in signing the Convention on Long-Range Transboundary Air Pollution under the UN Economic Commission for Europe (Economic Commission for Europe 1979). Subsequently, Canada assumed a leadership role in the development of a sulphur emission reduction protocol, signed in Helsinki in 1985, that committed member countries to a 30% emission reduction by 1994 (Economic Commission for Europe 1985*a*). As an adjunct to this protocol, Canada assumed a lead role to organize a program to monitor the effects of acidification in member countries and the benefits of control programs as they are instituted (Economic Commission for Europe 1985*b*). To permit an open international exchange of knowledge and publication of collected information, Canada sponsored and organized "Muskoka '85," an international symposium on acid rain (Martin 1986). Canada has achieved worldwide recognition for its involvement and leadership in the issue of environmental acidification.

ENVIRONMENTAL ACIDIFICATION AND THE FUTURE

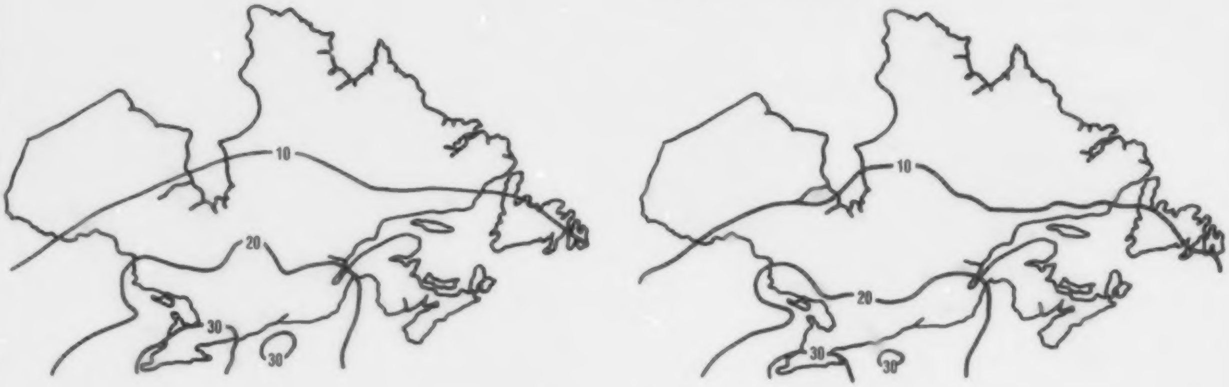
Benefits of controls

Information in Figure 24.4 and in the discussion of control strategy in this chapter illustrates that the emission of sulphur in eastern Canada has declined over the past decade. The decline has made it possible to verify the dose–

FIGURE 24.12

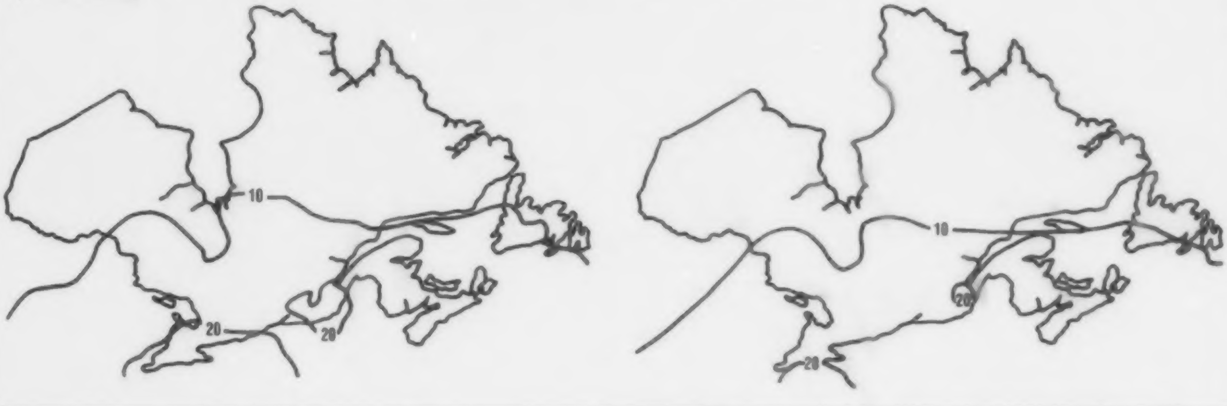
Sulphate deposition patterns (in kilograms per hectare per year) projected for four emission control scenarios

The benefits of Canada–U.S. cooperation are evident in 3 and 4.



Scenario 1
No change. The amount of sulphate in precipitation remains at 1982–86 levels.

Scenario 2
The projected levels of sulphate in precipitation if Canadian emissions are reduced by 50%, which is the objective for 1994. No U.S. controls.



Scenario 3
The projected levels of sulphate in precipitation including both Canadian cutbacks described in scenario 2 and emission reductions in the eastern United States of 5 million tons (4.5 million tonnes).

Scenario 4
The same as scenario 3, except that the emission reductions in the U.S. are increased to 10 million tons (9 million tonnes).

response relationships on which the control strategies have been based. A decline in sulphate deposition in Nova Scotia apparently resulted in reduced acidity in 11 rivers between 1971–73 and 1981–82 (Thompson 1986). In the Sudbury area, where emissions declined by over 50% between 1974–76 and 1981–83, a resurvey of 209 lakes shows that most of them became less acidic (Keller and Pitblado 1986). Surveys of 54 lakes in the Algoma region of Ontario showed a rapid response to a decline in sulphate deposition. Two lakes that in 1979 had a pH below 5.5 and were without fish have recovered sufficiently that their populations have been reestablished (Kelso and Jeffries 1988). Evidence is accumulating to support the benefits that were projected as a consequence of emission controls. This, in turn, provides increased confidence in the projections.

Models of atmospheric transport and deposition have been used to estimate the levels of acidic sulphate deposition that would be expected over Canada and the United States as a result of different degrees of sulphur emission control. These estimates considered four possible scenarios:

1. Sulphur dioxide emissions remain at 1980 levels.
2. Canadian sulphur dioxide emissions are reduced by 50% per the 1994 control strategy objective.

3. In addition to scenario (2), sulphur dioxide emissions are reduced by 5 million tons (4.5 million tonnes) in the United States.

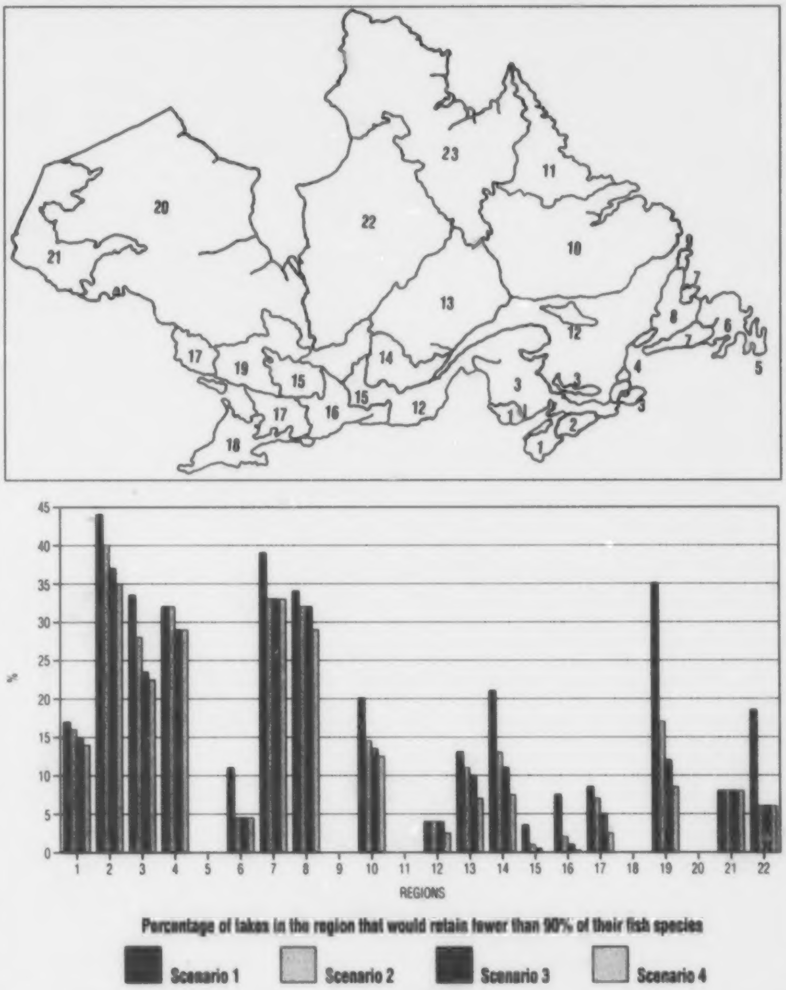
4. A 10-million-ton (9-million-tonne) reduction of sulphur dioxide emissions in the United States is added to scenario (2).

Figure 24.12 shows the projections of sulphate deposition for each of these scenarios (RMCC 1990, part 3). These levels of deposition have subsequently been used in models of aquatic systems to project the expected degree of acidification of lakes and the resulting impoverishment of fish species (i.e., the percentage remaining of the number of species present before acidification) under each of the scenarios. Figure 24.13 shows the projected relative benefits of the four scenarios, expressed in terms of fish, indicating the percentage of lakes in each region that would be expected to retain less than 90% of their fish species. Other organisms in aquatic ecosystems may be expected to react similarly (RMCC 1990, part 4).

The figure shows that emission controls provide a much greater benefit to the Ontario–Quebec area than to the highly sensitive lakes of the Atlantic provinces. Even with the U.S. controls in place, the modelled results indicate that some sensitive regions will still be expected to lose more than 10% of species in more than 30% of their surface waters. For the whole of eastern Canada, the area suffering damage would be reduced from about 100 000 lakes (13%) to about 39 000 lakes (5%) as a result of reductions of 50% from the 1980 emission levels in both Canada and the United States.

FIGURE 24.13

Potential for improvement to aquatic ecosystems under the same four emission control scenarios described in Figure 24.12



Source: RMCC (1990, part 4).

Prospectus

Based on research findings to date, the agreements currently in place between government and industry have succeeded in reducing acidic deposition in Canada, and scheduled emission reductions have also been legislated in the United States. Reductions of sulphur emissions will result in greatly improved aquatic habitat; however, even after present control targets are achieved, the acidification of many aquatic ecosystems, particularly in highly sensitive lands in the Atlantic provinces, will likely continue. The target loading value of 20 kg/ha per year has been confirmed as suitable only for moderately sensitive water bodies; a target value of 8–12 kg/ha per year would be required to protect more biologically sensitive waters (Long-Range Transport of Air Pollutants Program 1990). Although no quantitative projections are yet possible for forests, human health, or materials damage, it must be assumed that there will also be some degree of qualitative improvement in these categories.

It may be necessary for Canada to negotiate further reductions in emissions from specific sources. And, although recovery of ecosystems has been documented in various parts of eastern Canada, it is unclear how completely and how quickly the damaged ecosystems will recover.

Monitoring programs must be continued to provide the critical environmental indicators that are necessary to establish the degree to which actual ecosystem responses match the predicted results. Future judgements will be required as to the adequacy of control measures to achieve levels of protection that are acceptable to Canadian society. Comprehensive and reliable environmental monitoring information will be essential in making those judgements.

The most immediate solutions behind "acid rain" are typically associated with our efforts to control the major sources of emissions. We have made significant progress through cooperative actions between governments and between governments and industries. However, the long-term solution is much broader than this. Modern society's ongoing demand for more energy and more industrial production is truly the crucial factor. Protecting our environment and ourselves will ultimately depend on the actions that we are willing to take as individuals, as communities, as corporations. We will undoubtedly need to collectively devise different and innovative approaches to the use of energy, and of goods and services.

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25

COURTESY OF CANADIAN WILDLIFE SERVICE, OTTAWA

HIGHLIGHTS

There are few sound scientific data available on municipal solid waste at the national level. This lack of uniform baseline data and past failure to monitor trends impede efforts to evaluate the scope of the acknowledged garbage crisis.

■

Canadians are among the highest generators of municipal solid waste in the world on a per person basis. During the 1980s, Ontario's per capita waste generation is estimated to have increased by as much as 25%.

■

In terms of environmental impact, the waste of raw materials and energy and the degradation of ecosystems that today's throwaway mentality encourage are the most serious aspects of the garbage problem.

■

Paper is the most common material in the municipal waste stream; it comprises about 35% of the total. Approximately one-third of garbage, when analyzed by product type, is discarded packaging.

■

Landfills (about 10 000 in Canada) are currently the most common form of garbage disposal. Most Canadian landfills are closer to rudimentary dumps than to state-of-the-art landfills.

■

Incineration is also used as a disposal technique. Incinerators emit acid gases, carbon dioxide, and toxic chemicals, although modern incinerators produce much lower levels of pollutants. In addition, incinerators always produce large quantities of ash, which must often be disposed of in facilities licensed to treat hazardous wastes.

■

New approaches to the management of solid waste halt or slow down the use of natural resources. Governments are giving priority to the "4 Rs": reduction (of use of resources in the first place), reuse, recycling, and recovery (primarily of energy by burning waste).

■

The Canadian Council of Ministers of the Environment has set a nationwide goal for waste reduction of 50% by weight per person, from 1988 levels, by the year 2000.

■

So far, Ontario's blue box curbside recycling program, the longest-running curbside program, has diverted only 3–4% of Ontario's municipal solid waste.

■

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> **“Canadians have become accustomed to a high throughput consumer society that takes for granted obsolescence, a high rate of consumer spending and an almost total disregard for waste — both individually and socially. To continue to follow the wasteful path will lead to a society in which costs of resources will continually rise, energy will become increasingly scarce, and environment will deteriorate.”**
>
> — Science Council of Canada (1977)

INTRODUCTION

Canadians are among the largest producers of garbage in the world. Despite the public's increasing awareness of the need to conserve ecosystems and resources by extracting less and reusing and recycling more, the unceasing flow of rubbish from ordinary everyday activities has not yet diminished. In fact, indications are that our waste generation has speeded up in recent years. The Ontario Ministry of the Environment (1990) recently estimated that the amount of waste that Ontarians produce has increased by as much as 25% per person over the last decade. According to a 1989 survey, Canadians generated approximately 30 million tonnes of municipal garbage (including light industrial, commercial, and institutional wastes) and construction wastes[1] in 1988 (R. Christensen, Environment Canada, personal communication).

Most rubbish generated by Canadians ends up in landfill sites, although some is first incinerated to a fraction of its weight, and some is diverted out of the waste stream for recycling or reuse (Fig. 25.1). (Litter — everything from abandoned cars to six-pack rings strewn over forests, parks, roadsides, waterways, and oceans — is not included in the discussion in this chapter, as no data on the amount of litter produced by Canadians or its composition are available.) The recent unwillingness of neighbourhoods to have new landfill sites or incinerators located in their midst has triggered long-overdue research into the garbage problem. New initiatives should lead to a reduction in the total quantity of garbage produced in Canada by the mid-1990s. The Canadian Council of Ministers of the Environment has set a nationwide goal of a 50% reduction, by the year 2000, in the per person weight of garbage sent for disposal (CCREM 1989), down from the 1988 rate of an estimated 1.8 kg per person. Some provinces, including Ontario, have also adopted this goal (Ontario Ministry of the Environment 1990). Figure 25.2 shows Canadian garbage production by province and territory, according to a study done for the National Task Force on Packaging (CCME 1989*a*).

Included in the large amount of garbage produced in Canada are many products and by-products of modern technology that pose difficult challenges for waste managers. Nonhazardous manufactured goods, such as paper printed with metal-based ink, have the potential to pollute whether they are recycled, incinerated, or disposed of in landfill sites. If the paper in the example is disposed of in a landfill, the metal may leach into groundwater; if it is incinerated, the metal will contaminate the ash from the incinerator; and if it is recycled, "de-inking" may transfer the metal to the sludge, the wastewater, or the new product (Colborn *et al.* 1990).

The greatest impact that the production of large amounts of garbage has on the environment is not from the pollution attendant upon its disposal, however. Even more serious aspects of the garbage problem, in terms of environmental impact, are the use of materials and energy and the degradation and depletion of ecosystems that the "almost total disregard for waste" encouraged. The serious implications of overuse of renewable, replenishable, nonrenewable, and nonreplenishable resources for the health of the Ecosphere are set out in Chapter 1. The failure to conserve also adds to overall environmental costs through the air and water pollution generated by the manufacture of goods from resources that are not being conserved. By participating in recycling and waste reduction programs, Canadians not only reduce the immediate problem of garbage disposal but also accept personal responsibility for conserving the Earth's resources.

WHAT IS MUNICIPAL SOLID WASTE?

One of the difficulties in trying to establish a national picture of all solid waste generated in Canada is the unavailability of sound scientific data at the national

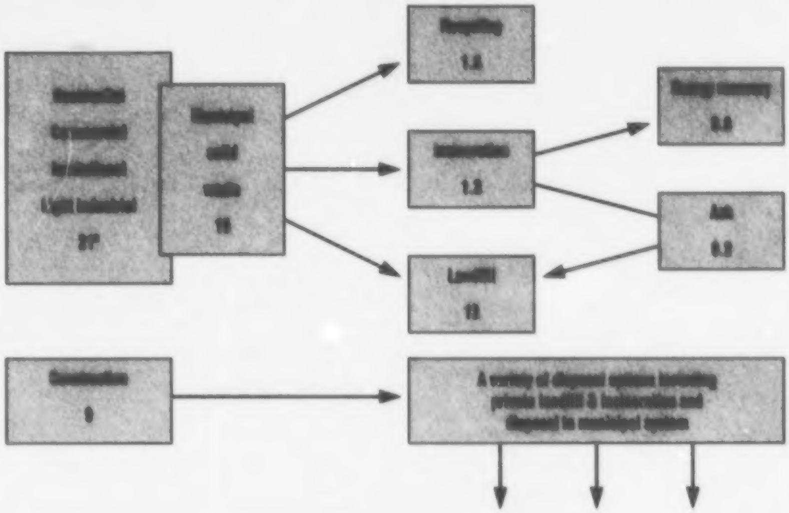
---

[1] Although a lot of research into solid waste in Canada is now going on, in the past there have been few Canada-wide studies. Consequently, the categories used in this chapter are not as rigid as they should be, and the measurements provided are usually approximations.

FIGURE 25.1

The management of municipal solid waste in Canada in 1988

The figure shows the amounts (in millions of tonnes) being recycled and going to landfills and incinerators, including amounts used as feedstocks in energy-from-waste operations. About 5 million tonnes from residential (e.g., ash from apartment incinerators), commercial, institutional, and light industrial sources are disposed of outside the municipal waste stream. About 9 million tonnes of construction waste are disposed of, an unknown percentage of that to municipal landfill sites.



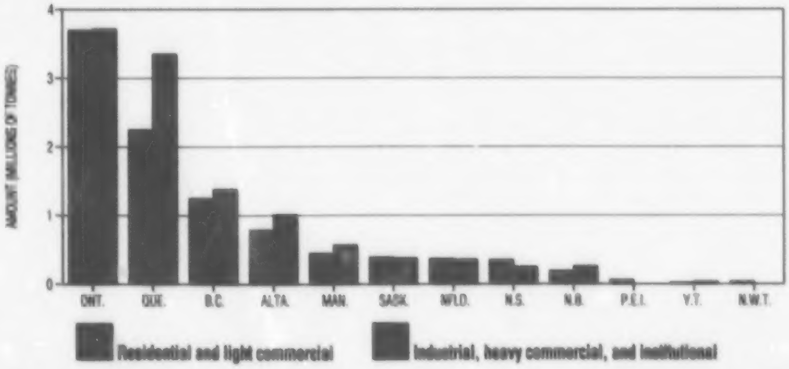
ª This number differs from some others that have been published for waste generation in Canada because the different studies have varied in their definitions of what is included as institutional, light industrial, and commercial waste.

Source: Based on unpublished data from Environment Canada, Waste Management Branch.

FIGURE 25.2

The amount of solid waste (in millions of tonnes) generated in Canada in 1988, by province and territory

The total comes to 20.5 million tonnes. It differs slightly from the total in Figure 25.1 because of differences in how the data were gathered.



Source: CCME (1989*a*).

level. Therefore, this chapter focuses on the approximately 16 million tonnes of Canada's solid waste that are considered municipal solid waste. This is a category for which statistics are available, although flawed. Solid wastes not included in the municipal waste stream are discussed elsewhere in this report.[2]

Municipal solid waste generally includes residential and light industrial, commercial, and institutional solid waste that is collected by the municipality or by a contracted collector on behalf of the municipality. Another definition of municipal solid waste is all the waste that is going into the municipal landfill or other facility. This second definition includes more material than the first: most municipalities do not pick up from all commercial establishments, industries, institutions, and apartment buildings, so the waste is hauled to the landfill by the waste generator or by a hauler contracted by the building management. Municipal solid waste is an administrative category, and it includes different materials in different municipalities. Construction and demolition wastes, old cars, and "white goods" (used appliances) are examples of the types of garbage that may be included in statistics from some municipalities and not others.

In most provinces, the provincial government sets standards for disposal of municipal solid waste and provides a regulatory function, whereas municipalities are responsible for the actual collection and disposal of garbage. The Province of New Brunswick has established a solid waste commission that will oversee collection, disposal, waste reduction, recycling, and similar programs on a province-wide basis. In the Yukon and Northwest Territories, responsibility is shared between the municipalities and the territorial governments.

---

[2] Hazardous wastes that are in hazardous waste sites are dealt with in Chapter 14, which also deals with nontoxic industrial sludges that cannot be recycled, radioactive wastes, and other wastes from industrial processes that do not become part of municipal garbage (e.g., wastes from car manufacturing, ash from industrial boilers). Also, municipal solid waste does not generally include mine tailings (see Chapter 11), foundry sand, forestry slash, sewage sludges, and dredged material.

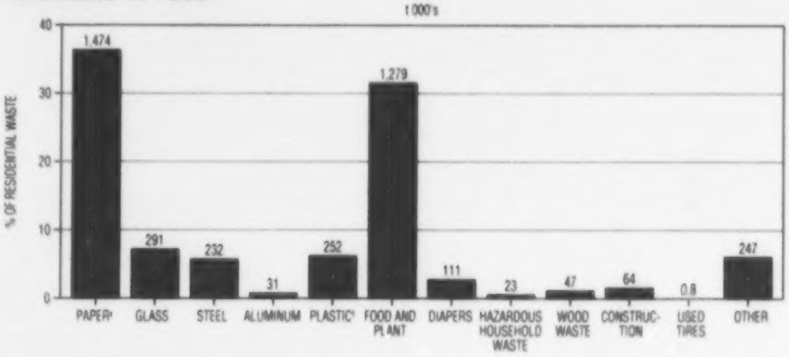
THE SECTORS THAT GENERATE MUNICIPAL SOLID WASTE

Garbage arrives at the municipal waste site, which may be a dump, sanitary landfill, incinerator, or recycling depot, from residences, commercial establishments, industries, and construction sites. Note that not *all* refuse from each of these sources enters the municipal waste stream (see Fig. 25.1): at one extreme, almost all of the residential garbage does (although a small amount is burned in apartment incinerators); at the other extreme, most of the construction waste does not.

In 1988, residential wastes made up about 35–40% of the total quantity of trash hauled to municipal landfill. Figure 25.3 shows what materials were in residential garbage in Ontario in 1989, and how many tonnes of each material were thrown out each year. A small but important part of the household waste stream is household hazardous waste, including bleach cleaners, disinfectants, and batteries. Household hazardous waste has the potential to damage the environment to a greater extent than regular garbage. If these wastes were being dumped by industry in large quantities, they would be subject to government regulation and control (see Chapter 14) and in many cases would not be allowed into the landfill at all. Unfortunately, when they come in small quantities from homes, mixed in with regular garbage, they often do reach the landfill. Because of the large quantities involved, made up of lots of small amounts from Canada's 10 million households, reduction of household hazardous waste is a critical environmental priority.

FIGURE 25.3

The composition of the residential waste generated in Ontario in 1989



[a] **Paper and paperboard**	**tonnes**
Newsprint	673 200
Fine paper	74 000
Boxboard	173 100
Old corrugated cardboard	108 900
Magazines	165 100
Mixed paper (waxed/plastic/mixed)	59 300
Phone books	13 000
Composite packaging	11 400
Other (kraft, wallpaper, tissue)	196 000
Total	**1 474 000**

[b] Containers made of PET (polyethylene terephthalate) and HDPE (high-density polyethylene), such as soft drink bottles, are relatively easy to identify, and these types of plastic are not degraded significantly by recycling. These containers are the most likely candidates for inclusion in programs to recycle postconsumer plastics.

Source: Ontario Ministry of the Environment (in press).

Commercial wastes are generally defined as those wastes that come from businesses other than industries: for example, stores, offices, and restaurants. Various types of paper and paperboard often make up a large percentage of commercial waste. Commercial wastes may sometimes include those of institutions, such as hospitals, schools, and airports, which produce, in addition to paper, special or hazardous wastes from some part of their operations. For example, airport wastes may contain leftover food from international flights; this food may be contaminated with foreign organisms that could infect plants and/or animals in Canada. Hospital garbage contains needles, contaminated clothing and swabs, and body parts. These hazardous wastes are generally required to be segregated from the regular municipal waste stream.

Industrial wastes can be broken down into a number of categories, including raw material wastes (e.g., tree bark in a sawmill), process wastes (e.g., sludges from metal plating), packaging wastes (e.g., shipping containers), and products that have not been manufactured to the required standard. The range of industrial wastes reflects the wide range of industries in Canada. Waste from light industry (e.g., packaging manufacturers) is usually directed into the municipal waste stream, whereas waste from heavy industry (e.g., car manufacturers) is not. Table 25.1 lists the component materials in about 5 million tonnes of garbage discarded by commercial establishments, institutions, and a mixture of light and heavy industries in Ontario in 1989.

TABLE 25.1

A breakdown of waste from commercial establishments, institutions, and a mixture of light and heavy industries in Ontario in 1989

The table does not include waste from
- construction/demolition not disposed of in public landfills
- contaminated soil and cleanup of spills
- road construction, maintenance
- dredging of water bodies

nor does it include the following materials:
- foundry sand
- blast furnace slag
- fly and bottom ash
- compost
- sewage sludge

Component	1989 (t)	%
Old corrugated cardboard	441 000	8
Office paper	354 000	7
Other paper	426 000	8
Wood	1 130 000	21
Glass	282 000	5
Plastic	163 000	3
Plant and yard wastes (organics)	600 000	11
Metal	599 000	11
Tires	88 000	2
Other	1 278 000	24
Total	**5 361 000**	**100**

Source: Ontario Ministry of the Environment (in press).

WHAT GOES INTO THE GARBAGE?

An up-to-date source of data on the composition of municipal solid waste across Canada does not exist. No recent comprehensive study has been done to determine waste composition for Canada as a whole. A survey done for the National Task Force on Packaging (CCME 1989*a*) looked at generation throughout Canada, but it provided a comprehensive picture of the composition of waste only insofar as packaging was concerned.

Quebec and Ontario have done studies (Ministère de l'Environnement du Québec 1988; Ontario Ministry of the Environment, in press). These do not necessarily reflect the national picture; however, the Ontario study is arguably the most comprehensive recent Canadian study of how waste is generated and what it contains (Fig. 25.3 and Table 25.1). The results of the Ontario study cannot be directly compared with the results of the national packaging survey, however, as different types of garbage were included in the two studies. The Ontario study, for example, included wastes from heavy industry and manufacturing; there were not included in the national survey.

The Ontario study sorted municipal solid waste into materials. As can be seen in Figure 25.3 and Table 25.1, garbage is a real hodgepodge: no one material makes up more than a small percentage of the total. Paper waste, to take just one example, is not homogeneous: it comprises newspapers and fine paper, cardboard, magazines, phone books, wallpaper, tissues, and much more. Often materials look similar but actually have different properties. For example, heat-treated glass, such as a broken casserole, differs from window glass. Other wastes are difficult to recycle because they are made up of mixtures of materials. Burned-out light bulbs, for example, are made up of at least two or three different kinds of metals, glass (which differs in composition from window glass or heat-treated glass), interior coatings, and adhesive cement. Materials may also have become contaminated with other wastes as a result of the use to which they were put. For example, paper hamburger wrappers are often coated with mustard, ketchup, onions, and pieces of hamburger.

The most common family of materials in the waste stream is paper and paperboard, which includes everything from newspapers to tissues, office paper, wrapping paper, and cardboard boxes (Fig. 25.3 and Table 25.1). This category makes up over one-third of the total municipal solid waste. Canada consumed about 6 million tonnes of paper and paperboard products in 1988 (Environment Canada and Forestry Canada 1990). Although about 1.6 million tonnes were recovered for recycling, the remaining 4.6 million tonnes of paper products that were thrown away as waste represent over 100 million trees.

Yard waste, generally grass clippings and leaves with some hedge clippings and prunings, is the second largest family of materials in the waste stream. Food waste, metal, plastic, and glass are other major components. The cumulative result of each Canadian using a small amount of a product can be quite enormous; for example, Canadian homes produce more than 1 800 t of empty glass jars and bottles and 1 400 t of steel food and beverage cans every day of the year.[3]

Municipal solid waste can be measured by volume or by weight, and the percentages of its component materials will vary depending on which method is used (Fig. 25.4). Some materials take up a lot of room but are quite light; plastic, for example, represents 18% of the waste stream when it is measured by volume, but only 7% when it is measured by weight. Glass is much more dense, so it is a small percentage by volume but a larger percentage by weight. This difference is important according to the use to which the data will be put. If the concern is the size of landfills, volume is the important

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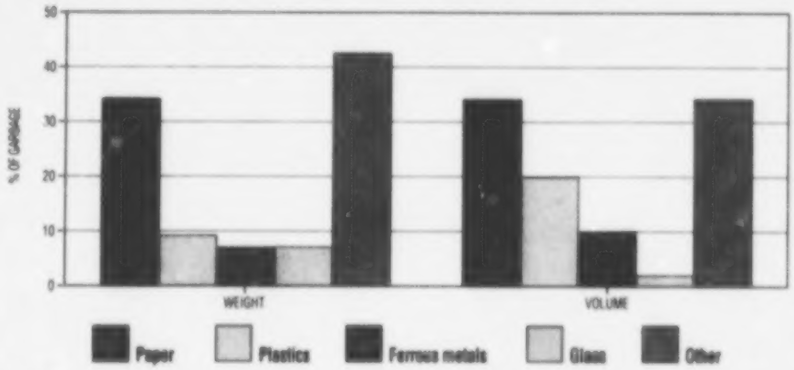
[3] The numbers for Canada have been derived based on Ontario data (CCME 1989*a*).

FIGURE 25.4

A comparison of the relative importance, by weight and by volume, of the various types of garbage in the U.S. municipal solid waste stream

Note that plastic makes up a larger percentage of garbage by volume than it does by weight and that the situation is reversed for glass. Canadian proportions are not available, but the reader can assume that they would be similar.

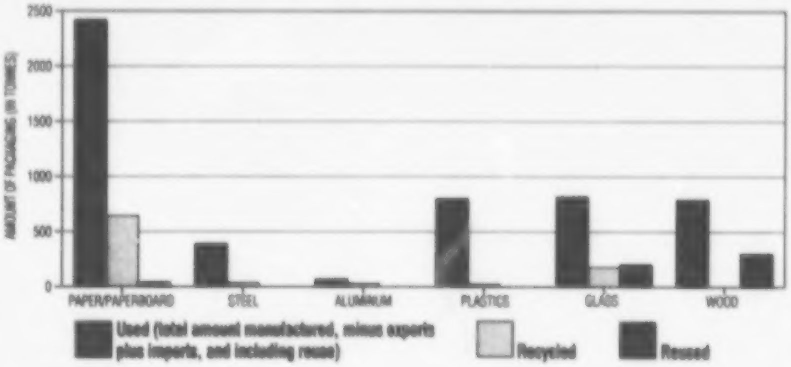


Source: Based on data from U.S. Environmental Protection Agency (1990).

FIGURE 25.5

The amount of packaging material (in tonnes) that was used in Canada in 1988, including the amounts that were recycled and reused

Packaging that enters or leaves the country on products is not included in the totals.



Source: CCME (1989*a*).

measure. If the concern is the waste of resources, weight is a much better indicator than volume of the amount of raw material that went into a product. The amount of raw material in a foam plastic container is likely to be very much less than the amount of raw material in a similarly sized paper or glass container (although recyclability and wastes associated with the manufacturing process must also be considered).

Garbage can also be categorized by product type. In Canada, packaging is the product type that has been scrutinized most closely. According to the National Task Force on Packaging, over 5 million tonnes of packaging are used in Canada (based on production and imports for use on Canadian goods, minus exports of packaging to be used abroad) (Fig. 25.5), but the survey did not include packaging that was already on products when they were imported. Packaging consists of shopping bags and the protective and promotional wrap on goods, as well as bottles, cans, shipping cartons, plastic sheeting, pallets, and other industrial packaging that the householder never sees. Paper makes up the largest single component of packaging by weight, but plastics, glass, wood, steel, and aluminum are important as well. Much packaging is already being recycled, and a small percentage, especially glass (refillable bottles) and wood (industrial pallets), is being reused.

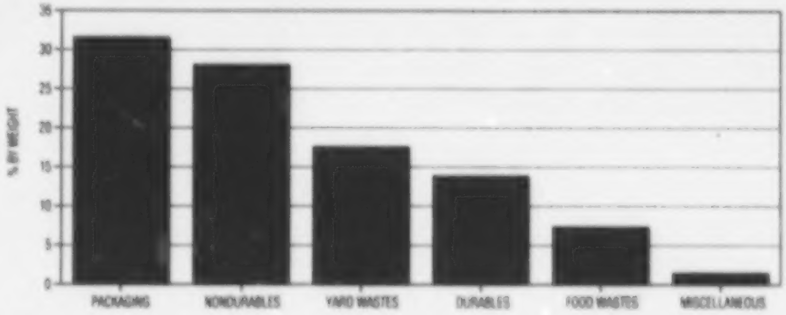
The U.S. Environmental Protection Agency has categorized garbage into several product types in addition to packaging: durables, nondurables, yard wastes, food wastes, and miscellaneous (U.S. Congress, Office of Technology Assessment 1989). It found that, after packaging, the next largest component of the waste stream is nondurables, a category that includes disposables such as newspapers, disposable razors, and pens, as well as books and clothing — perhaps because they are often thrown out before they wear out. If the percentage of nondurables in municipal solid waste in Canada is calculated using the U.S. proportions illustrated in Figure 25.6, it appears that Canadians throw away more than 4.5 million tonnes of nondurable products each year.

If the U.S. proportion for durables, the fourth largest category, is applied to Canada's total municipal solid waste, 2 million tonnes of durable products are discarded in Canada each year. This category includes major appliances, furniture, rubber tires, and many other items that were manufactured for extended life but have become worn out or broken down.

FIGURE 25.6

Percentages by weight of nondurables, durables, packaging, yard wastes, food wastes, and miscellaneous in the U.S. municipal waste stream in 1988

Nondurables are newspapers, books, magazines, tissue paper, office and commercial paper, clothing, footware, and miscellaneous. Durables are major appliances, furniture, rubber tires, and miscellaneous. Canadian proportions are not available, but the reader can assume that they would be similar.



Source: U.S. Environmental Protection Agency (1988).

TABLE 25.2

The levels (in parts per million) of some heavy metals found in leachate from a municipal landfill

Heavy metal	Range in raw leachate	Ambient water quality guidelines for protection of freshwater aquatic life[a]
Arsenic	< 0.001 – 0.011	0.05
Cadmium	< 0.001 – < 0.003	0.0002 – 0.0018
Copper	0.3	0.002 – 0.004
Lead	< 0.006 – 0.043	0.001 – 0.007
Manganese	0.5 – 4.73	No guideline[b]
Zinc	0.12 – 1.38	0.03

[a] These levels cannot be applied to raw leachate. They apply to water quality in streams and lakes. Leachates in the ranges shown on this table would be below the ambient guidelines once they entered surface water.

[b] The drinking water guideline for manganese is ≤ 0.05 ppm.

Source: Greater Vancouver Regional District (1988). Water quality guidelines are taken from a summary pamphlet (Environment Canada and Health and Welfare Canada, no date).

CURRENT DISPOSAL PRACTICES

Garbage has always been viewed as something that must be "gotten rid of." Unfortunately, in terms of convenience, or fortunately, in terms of conservation of resources, garbage does not magically disappear. Indeed, the waste heaps, or middens, of early aboriginal peoples have hardly changed over the centuries since they were left, although the absence of hazardous materials means that the middens pose no threat to the environment today. The relatively small quantities of waste from entirely natural sources have decayed into soil, and the bones, stones, pottery, and other durable materials remain for study by archaeologists.

Today, Canada is building some impressive "middens" for future generations of archaeologists to investigate. In 1988, 13 million tonnes of municipal garbage ended up in Canada's 10 000 landfills, including the 200 000 t of ash that is left over from incinerating what would have been a further 1.3 million tonnes of municipal waste. To reduce its bulk, the refuse is often compacted in specially designed trucks during collection, at transfer stations on the way to the disposal site, and/or at the landfill.

Landfills

Landfilling is by far the most common waste management option used by municipalities in Canada today (see Fig. 25.1). Many landfills are no more than rudimentary garbage dumps: the garbage is left on the ground and allowed to degrade until covered with other loads of garbage. Some are sanitary landfills, landfills that are controlled to prevent dumping of hazardous materials and at which precautions are taken to protect public health and safety and to protect the natural environment (see Box 25.1). Landfills identified as hazardous waste sites are discussed in Chapter 14.

Typical landfills produce thousands of litres of leachate, which is a sort of "tea" brewed when garbage sits in rainwater or groundwater or when liquid or decomposing garbage contaminates the precipitation that percolates through the garbage. Landfills will produce leachates at different rates depending on the type of surface and the methods of construction and operation used. Problems occur when leachates contaminate groundwater and surface water, thus poisoning drinking water and, possibly, the food chain. In a few recently constructed sanitary landfills, engineered liners of compacted soil and/or synthetic materials and a network of pipes channel the leachate either into treatment centres before it leaves the site or into municipal sewers so that it can be treated by the municipal sewage treatment plant. If not collected, the leachate can pollute streams and underground waters. The levels of contaminants in leachate are low (Table 25.2). Nevertheless, heavy metals, such as lead and cadmium, are potentially of concern because they can bioaccumulate (see also Chapter 21).

TABLE 25.3

Components of landfill gas at a site that was used for municipal solid waste and industrial waste

The results are not representative of emissions from a municipal landfill site operating by today's standards; however, they represent the legacy of closed sites that operated under less stringent pollution standards. They were obtained by averaging results at seven sampling locations at one landfill.

Main components	**% of total gas emitted**[a]
Methane	53.4
Carbon dioxide	24.9
Nitrogen	9.6
Oxygen	0.9
Other hydrocarbons[b]	0.1

[a] The individual percentage values for methane, carbon dioxide, oxygen, and nitrogen may vary by ±3%; hence, the total does not add up to 100%.

[b] Includes dichloromethane (0.5 ppm), benzene (1.5 ppm), toluene (13.3 ppm). All are on the Priority Substances List for immediate assessment by the *Canadian Environmental Protection Act* (see Chapter 21).

Source: Upper Ottawa Street Landfill Site Study (1986).

BOX 25.1

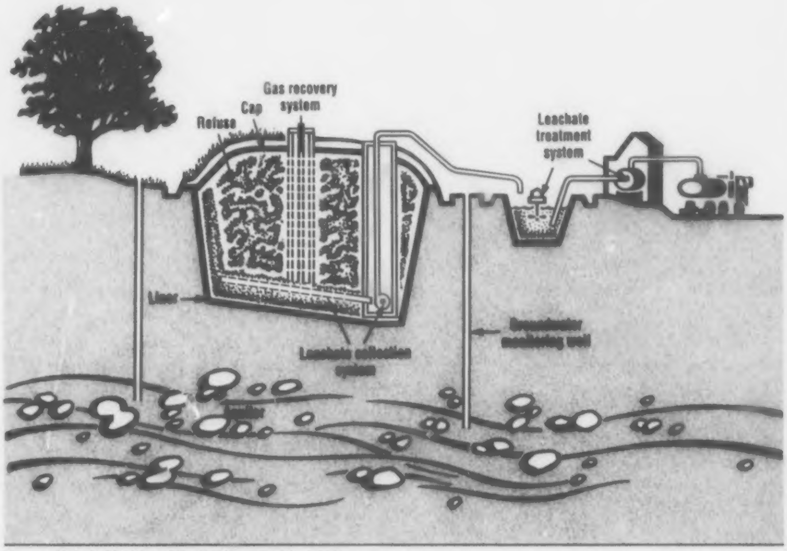
High-tech garbage dumps

Distant cousins of the rudimentary town dump, which was sometimes inappropriately sited and where there was little control over what was dumped or how the waste affected the surrounding environment, state-of-the-art landfills (Fig. 25.B1) are carefully sited, equipped with collection systems for leachates and landfill gases, open only to approved types of wastes (except for the hazardous household substances in municipal solid waste), and monitored and maintained for as long after they are finally shut down as is necessary. As a result, a sanitary landfill can be phenomenally expensive. Table 25.B1 shows hypothetical costs for three landfills of different sizes and with different types of leachate collection systems. The most expensive single item in each case is the continuing care of the landfill after it has closed.

At present, most Canadian landfills are closer to the rudimentary dump than to the state-of-the-art landfill. All contain hazardous household waste. Some contain a large mixture of toxic and heavy industrial wastes, a daunting legacy of a time when everyone was less aware of the dangers of water, soil, and air pollution.

FIGURE 25.B1

A sanitary landfill with leachate collection and gas recovery


Gas recovery system
Cap
Refuse
Leachate treatment system
Liner
Groundwater monitoring well
Leachate collection system
Aquifer

Source: Ontario Ministry of the Environment (in press).

Landfills also produce "landfill gas": primarily methane, from the anaerobic breakdown of organic matter in the buried garbage. This gas is contaminated with volatile substances, many of which are toxic, that it collects as it rises through the landfill. Table 25.3 shows the components of gas emitted from a landfill site containing both industrial and municipal waste. The gas is not representative of gas from the average modern controlled landfill, but many of the older dump sites in Canada, some of which are still operating, were poorly controlled in the past and contain mixtures of municipal and industrial wastes that would not be allowed in today. Landfill gas is sometimes collected and burned, or flared, at the landfill rather than being released to the atmosphere. Landfill gas can pollute the atmosphere, and methane from landfills contributes 49% of human-caused methane generated in Canada (A. Jaques, Environment Canada, personal communication). Atmospheric methane influences the global climate (see Chapter 22). Methane from landfills can also move horizontally through the ground, sometimes for many hundreds of metres, and find its way into buildings. Methane is explosive when mixed with air in certain concentrations: one of the reasons it is undesirable to locate buildings over or near closed landfill sites is because of the danger of methane explosion.

Landfill sites are also an environmental problem because they use land that is suitable for other purposes, such as agriculture, recreation, wildlife habitat, or housing. They can generate odours, dust, and litter, and they may attract

[illegible]

Hypothetical costs for three landfills of different sizes and characteristics

	Scenario 1	Scenario 2	Scenario 3
Total capacity (t)	100 000	2 000 000	20 000 000
Average haul distance (km)	30	20	20
Soils	Clay	Glacial till	Glacial till
Leachate management	Natural attenuation	Treat and pump to sewer	Treat and pump to sewer
Costs			
Tip fee required to recover costs	$96.39	$36.10	$23.24
Engineering approvals	$911 405.00	$1 443 514.00	$2 193 122.00
Compensation	$311 405.00	$543 514.00	$1 193 122.00
Construction	$790 950.00	$4 146 094.00	$24 262 799.00
Operating cost	$247 524.00	$2 417 762.00	$17 119 344.00
Equipment replacement	$441 088.00	$1 114 000.00	$1 114 000.00
Leachate treatment			
– capital costs	$229 088.00	$2 221 906.00	$10 146 607.00
– operating costs	$3 000.00	$167 148.00	$708 523.00
Total site closure	$19 460.00	$259 324.00	$2 709 692.00
Annual postclosure care	$29 631.00	$230 841.00	$1 211 234.00
Required closure fund	$1 084 908.00	$10 448 146.00	$61 823 712.00

Source: Ontario Ministry of the Environment (in press).

scavenging birds and wildlife. Truck traffic and heavy equipment create noise and fumes.

Landfills are becoming increasingly expensive to site, build, operate, monitor, and care for after closure (see Box 25.1). Based on a survey of 71 municipalities, conducted in 1990 for the Federation of Canadian Municipalities (1990), landfills serving 22% of the Canadian population will be full within two years. By 1995, existing landfills serving 71% of the population will be full. Because local opposition generally springs up wherever a new landfill site is proposed, it will be a difficult and expensive task to site the replacements for closed landfills.

Landfills pose a special challenge in northern Canada. In the Arctic, garbage is often piled on frozen ground, where rocks and gravel provide the only cover. Wastes of all kinds, including untreated sewage and industrial chemicals, often go into a single site. Little breakdown takes place because of the cold, and disease organisms survive in a frozen state a long time. The impact of the dump on the fragile arctic environment can be severe.

Incineration

Much of the garbage that is not landfilled is burned. In the past, most people incinerated a lot of garbage and it never entered the municipal waste stream. Some still burn papers and food scraps in woodstoves and leaves and other yard wastes outdoors.[4] Today some garbage is burned in the open air at landfills or in open pit municipal incinerators, and other garbage is burned in incinerators, some of which are designed to recover energy from the burning of waste. There are 16 municipal solid waste incinerators in Canada, each burning at least 15 t of waste per day. An estimated 1.3 million tonnes of municipal solid waste were incinerated in 1988, over half for energy recovery (see Fig. 25.1). Significant quantities of waste are burned in privately operated incinerators as well. For example, some apartment buildings burn their garbage in an incinerator located at or near the bottom of the garbage chute, and hospitals often burn their medical wastes.

For incinerators to fully combust waste, they must operate at a very high temperature. If the temperature is not high enough and if there are no adequate pollution control devices, burning of garbage can add significant amounts of toxic chemicals to the air (Tables 25.4 and 25.5). Newer facilities control emissions of toxic air pollutants and pollutants that cause acid rain but still contribute carbon dioxide, a greenhouse gas, and small amounts of acid gas to the atmosphere. Even incinerators that meet new guidelines — four, accounting for over 50% of the waste burned in Canada — produce ash. The ash from burning (bottom ash, 80% of total) and the airborne particles that are trapped by the air pollution control equipment (fly ash, 20% of total) are generally contaminated with toxic organic chemicals and heavy metals (Table 25.6). Incinerator ash should be tested and, where deemed hazardous, disposed of in a landfill licensed for disposal of hazardous industrial wastes. Approximately 100 000 t of ash were disposed of in Canadian municipal landfills in 1988, and another 100 000 t were disposed of in landfills specially designed for incinerator ash.

Experience to date has indicated that siting of incinerators is as difficult as the siting of new landfills. For example, the city of Windsor, Ontario, recently fought the startup of an incinerator in nearby Detroit, Michigan, by suing for more effective, and consequently more costly, pollution control equipment than was planned (Colborn *et al.* 1990).

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[4] The burning of garbage and leaves at relatively low temperatures, as occurs in woodstoves and backyard bonfires, results in the formation of large airborne particles and soot. Soot can build up in the chimneys of woodstoves, blocking the flow of hot air. This may result in the release of toxic air pollutants into the house or cause the woodstove to explode. Out of doors, smoke and soot can impair visibility as well as cause short-term health problems, such as coughing, eye irritation, and bronchial and asthmatic attacks. These particles are also likely to be contaminated with toxic chemicals, such as PAHs, dioxins, and furans (see Chapter 21).

Guidelines set by the Canadian Council of Ministers of the Environment (CCME) for incinerator stack emissions of four contaminants — hydrogen chloride, carbon monoxide, total dioxins and furans, and suspended particulate matter

These reduced emissions are considered safe. They are possible where incinerators are equipped with pollution control devices (dry scrubber fabric filter systems), combustion conditions are good (meaning there is a good mix of combustible wastes), and 11% of the mixture is oxygen. The levels emitted by an incinerator with no air pollution control are shown for comparison.

	Present CCME guidelines		**Obsolete incinerator with no air pollution control**[b]
Contaminant	**Levels**[a]	**Monitoring method**	
Hydrogen chloride (HCl)	75 mg/m^3 (50 ppmdv), or 90% removal[b]	Continuous, based on 24-hour running average	430 ppmdv
Carbon monoxide (CO)	57 mg/m^3 (50 ppmdv)[c]	Continuous, based on 24-hour running average	150 ppmdv
Total dioxins and furans[d]	0.5 ng/m^3	As specified by responsible regulatory agency	250 ng/m^3
Particulate matter	20 mg/m^3	As specified by responsible regulatory agency	6 300 mg/m^3

ppmdv = parts per million dry volume

[a] All measurements (except those of dry volume) are of flue gases at a temperature of 25°C and a pressure of 101.3 kPa.

[b] The least restrictive of these requirements only.

[c] RDF systems should maintain a limit of 114 mg/m^3 (100 ppmdv).

[d] Measured as International Toxic Equivalency Factors, based upon tests for specific isomers (types) of dioxins and furans. (See Chapter 21 for an explanation of toxic equivalency factors.)

Source: The guidelines are from Canadian Council of Ministers of the Environment (CCME 1989*b*); some provinces may use them as the basis for regulations.

NEW DIRECTIONS IN WASTE MANAGEMENT

Canadians have identified waste management as one of the major environmental issues of the decade. Much has already been done to wean Canadians from their overdependence on disposal and ensure that necessary disposal is done to the highest possible standards. Opportunities for improvement remain. In 1990, the federal and provincial environment ministers adopted the National Packaging Protocol (see Box 25.2), a policy designed to substantially reduce the amount of waste going to landfill. Several provinces have established waste reduction targets. For example, British Columbia is considering banning certain materials (e.g., cardboard, batteries, tires) from landfill once markets for the recycling of these products have been established, and several Ontario municipalities have already implemented bans of this kind (e.g., cardboard, drywall, wood).

Most approaches to reduce the amount of waste going to landfill are based on the "4 Rs of waste management": Reduce, Reuse, Recycle, Recover. At least one province — Ontario — and several environmental groups have adopted an approach based on "3 Rs": Reduce, Reuse, Recycle. Some environmental groups add an R at the front of the list: Refuse, meaning that consumers should refuse to purchase items that are not essential or that will contribute excessively to waste.

The contribution that the 4 Rs make to waste reduction has been severely limited to date by the lack of consideration given at the design stage to the management of products as waste after their use by consumers. Given that the costs for managing these wastes have largely fallen to local governments in Canada, there has been little incentive to improve product design.

The increasing focus on waste management throughout the country, however, is now encouraging manufacturers to consider changes in product design in two critical areas:

- Design for recyclability — selecting materials that are recyclable, or removing materials that hinder the recycling process.
- Toxicity reduction — the removal of materials that complicate the management process at all stages of recycling through disposal — heavy metals in inks, chlorinated resins, chemical contaminants in glues and coatings, heavy-metal stabilizers in plastics — in favour of relatively benign substitutes.

Source reduction

Source reduction means reducing waste by not producing it in the first place. It can be achieved by living simply, by choosing reusable items over throw-away items (e.g., cloth shopping bags instead of either plastic or paper bags), by designing new products with waste reduction in mind, by using lighter-weight packaging or none at all, by improving industrial processes so they do not produce as much waste, and in many other ways.

Much source reduction can be implemented by individual choice. Some will require change to manufacturing or marketing practices. Yet more may be encouraged by legislation, outlawing wasteful products, or requiring conversion to less environmentally damaging systems.

It must be noted that, as used above, the term "source reduction" means reducing the amount of waste produced at the source. However, the term "waste reduction" is often used to mean reduction in the amount of waste going to landfill. The term "waste reduction"

Anticipated emissions of 11 contaminants (for which no incinerator emission guidelines have been established) from incinerators that operate within the guidelines of the Canadian Council of Ministers of the Environment (CCME) for the four contaminants in Table 25.4

The levels coming out the stack of an incinerator with no air pollution control equipment are given for comparison.

Contaminant	Anticipated typical emissions[a] from an incinerator meeting the CCME criteria	Emissions[a] from an obsolete incinerator with no air pollution control
Sulphur dioxide	260 mg/m³ (100 ppmdv)	260 mg/m³ (100 ppmdv)
Oxides of nitrogen (NO_x as NO_2)	400 mg/m³ (210 ppmdv)	400 mg/m³ (210 ppmdv)
PAHs	5 μg/m³	70 μg/m³
PCBs	1 μg/m³	3 μg/m³
Pentachlorophenol	1 μg/m³	2.7 μg/m³
Polychlorobenzene	1 μg/m³	12 μg/m³
Lead	50 μg/m³	34 000 μg/m³
Cadmium	100 μg/m³	1 500 μg/m³
Mercury	200 μg/m³	320 μg/m³
Arsenic	1 μg/m³	130 μg/m³
Chromium	10 μg/m³	2 000 μg/m³

ppmdv = parts per million dry volume

[a] All measurements are of flue gases at a temperature of 25°C and a pressure of 101.3 kPa.

Source: The guidelines are from Canadian Council of Ministers of the Environment (CCME 1989*b*); some provinces may use them as the basis for regulations. The other data have been supplied by the Office of Waste Management, Environment Canada.

TABLE 25.6

An analysis of the contaminants found in the bottom ash and fly ash from a municipal incinerator[a]

Compounds	Typical range of concentrations of some contaminants found in	
	Bottom ash	Fly ash
Organic compounds	(ng/g)	(ng/g)
Dioxins	ND – 0.16	0.7 – 1 040
Furans	ND	1.4 – 373
PAHs	0.23 – 968	18 – 5 640
Inorganic compounds	(μg/g)	(μg/g)
Cadmium	ND – 18	23 – 1 080
Chromium	984 – 3 170	86 – 1 070
Lead	1 000 – 9 900	1 400 – 26 000
Mercury	2.1 – 3.4	8.0 – 54
Zinc	1 300 – 5 210	4 700 – 70 000

ND = not detected

[a] Mass burn type incinerator.

Source: Sawell *et al.* (1990).

encompasses the concepts of reuse, recycling, and recovery. These definitions are not well established, and the terms are frequently confused.

Reuse

Reuse means repeated use of an item rather than throwing it away. The most obvious examples for many consumers have been beer and soft drinks in refillable money-back bottles rather than in single-use cans and plastic bottles. Items such as razors with replaceable blades, refillable pens, and repairable electrical appliances also lessen the quantity of waste because they last a long time. Organizations such as the Salvation Army run long-established repair and reuse systems for clothing, furniture, and appliances. Measurement of reuse is especially tough, but those few reuse programs that have been created recently have so far done little to reduce the size of the overall waste stream.

Recycling

Recycling means taking apart an old product and using the material it contains to make a new product. Sometimes the new product is identical to the old: for example, used glass containers can be melted down and turned into new glass containers, almost always with much less energy use and pollution than when the new product is made out of raw materials (Fig. 25.7). Another type of recycling, often called secondary recycling, creates a different kind of product from the original. For example, used plastics and mixed-material products such as drink boxes can be processed into lawn and garden furniture and similar items.

Despite the fact that not long ago recycling was an unfamiliar word to most people, it has actually been practised for a long time. For example, old cars have been recycled for almost as long as cars have been around. Sometimes the term "recycling" is also used to refer to the reuse of materials in products that never made it out of the factory, and this has also been going on for a long time.

BOX 25.2

Environmentally appropriate packaging

Ecologically minded shoppers who bring their own cloth bags to the grocery, who carry reusable cake boxes to the bakery, and who eagerly search out sources of unpackaged goods have a new ally. It is the National Packaging Protocol (NAPP), and what these shoppers are already doing, it recommends to everyone — from individual consumers to the packaging industry to retailers. A country-wide initiative of the Canadian Council of Ministers of the Environment, the voluntary protocol takes aim at the 35% of municipal solid waste that is packaging and recommends the following policies:

"1. All packaging shall have minimal effects on the environment."

The environmental consequences of packaging that must be weighed include depletion of virgin resources, disposal options, energy use in production and transport, and toxins produced during manufacture.

"2. Priority will be given to the management of packaging through source reduction, reuse, and recycling."

The preferred hierarchy is (i) no packaging, (ii) minimal packaging, (iii) reusable packaging, and (iv) recyclable packaging and packaging containing recyclable material. Standards and goals for recycled content in packaging, recycling/reuse infrastructure, and markets for recycled material are also addressed in this section of the NAPP.

"3. A continuing campaign of information and education will be undertaken to make all Canadians aware of the function and environmental impacts of packaging.

4. These policies will apply to all packaging used in Canada including imports.

5. Regulations will be implemented as necessary to ensure compliance with these policies.

6. All government policies and practices affecting packaging will be consistent with these national policies."

Already, the National Packaging Monitoring System has been established, and in April 1991, as part of this system, Statistics Canada distributed questionnaires to 10 000 establishments, asking about their use of packaging (R. Squires, Environment Canada, Waste Management Branch, personal communication). Recyclers will also be surveyed. A database drawn from these surveys will make it possible to monitor the following NAPP targets:

- By December 31, 1992, packaging sent for disposal (i.e., to a landfill or incinerator) shall be no more than 80% (by weight) of the amount sent in 1988.
- By December 31, 1996, the goal is 65%.
- By December 31, 2000, the goal is 50%.

There is general agreement, by most waste professionals and consumers, that Canada is in the midst of a serious waste crisis. The NAPP, which was put together by a task force representing all the provinces and territories, the federal government, municipalities, industries, and environmental groups, is a team approach to a solution to a highly visible aspect of the crisis.

Source: CCME (no date) and R. Squires, Environment Canada, Waste Management Branch, personal communication.

Many industries, such as the film plastic (as opposed to rigid plastic) industry, routinely return scrap product and offcuts from manufacturing processes to the melt hopper.

In the 1970s, many municipalities operated recycling bins or encouraged depots run by local companies or non-profit organizations. In each case, householders and businesses wishing to recycle materials could take them to the depot for recycling. Even today, many communities still operate recycling depots.

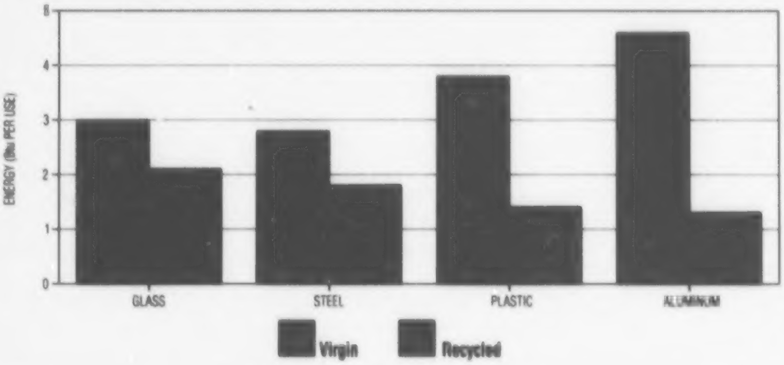
In 1985, plans were approved by the Province of Ontario for a large-scale program to recycle some components of the household waste stream. This program is based on the blue box®, a hard plastic container provided to households, which is used to segregate used newspapers, glass bottles, and cans from other garbage. Some municipalities also collect old corrugated cardboard and rigid plastic containers. Householders fill the blue box with recyclables and place it at curbside on a designated day. The blue box program has been jointly funded by municipalities, the provincial government, grocery producers, newspaper publishers, the plastic industry, the packaging industry, and the soft drink industry. By June 1990, more than 2 million street-level homes were served by a blue box program. Coverage is being extended to apartments and institutional and commercial establishments. There are also plans to extend the types of materials collected in the program. For example, some municipalities are experimenting with collection of compostable materials. Curbside collection programs are being put in place in most provinces.

It is difficult to measure the total quantity of material that is recycled. The Ontario Ministry of the Environment estimates that the curbside program is responsible for diverting more than 1 276 000 t of material from landfills between 1988 and 1991 (Table 25.7). The same ministry reports that its Industrial Waste Diversion Program

FIGURE 25.7

Actual energy savings from recycling glass, steel, and aluminum as opposed to using virgin resources, and theoretical energy savings from recycling plastic

Aluminum, which exhibits the largest savings, is correspondingly the leader in percentage recycled. Plastic, which shows the second largest savings, is not yet recycled in the primary sense (i.e., a plastic bottle is not recycled into a plastic bottle).



Source: Ross and Steinmeyer (1990).

TABLE 25.7

Material collected (in tonnes) by the blue box program in Ontario, 1988–91

Values for 1990 and 1991 are estimates only.

Material	**1988**	**1989**	**1990**	**1991**
Old newspaper	86 000	171 000	218 000	283 000
Glass	37 000	49 000	62 000	80 000
Cans and PET[a]	8 000	24 000	30 000	39 000
Miscellaneous[b]	–	–	34 000	55 000
Total	**131 000**	**244 000**	**344 000**	**457 000**

[a] PET makes up approximately 5%.

[b] Materials collected in expanded municipal recycling programs include rigid plastics, fine paper, old corrugated cardboard, and white goods (appliances).

Source: D.Onn, Ontario Ministry of the Environment, personal communication.

has diverted from landfill more than 530 000 t of nonhazardous solid waste, 73 000 t of hazardous waste, and 15 million litres of liquid industrial waste between 1987 and 1989. Some industries, such as the corrugated cardboard industry, report that a high percentage of postconsumer waste material has always been recycled.

Although depots continue to play a role in recycling, particularly in rural areas, curbside recycling is emerging as the dominant collection method in urban areas. As mentioned above, 2 million households in Ontario have blue boxes. Quebec estimates that, within seven years, 80% of all dwellings in that province will be served by curbside collection. In the western provinces, several hundred thousand households are involved. The Atlantic provinces are now beginning to establish curbside programs. Materials most commonly collected in these programs are newspapers, cans (aluminum and steel), glass containers, and sometimes plastics of specific types.

In addition to expanding the number of Canadian households being served by recycling programs, waste managers are coming up with new ways to serve the unique needs of different regions of the country, to improve program efficiencies, and to increase rates of recovery of certain materials. This has resulted in new collection vehicles and other specialized equipment; recycling programs that provide bags or larger storage containers for use in apartment buildings; and experiments with new approaches in which households are asked to separate all their household garbage into "wet" and "dry" for processing into recyclable fractions and compost.

Recycling programs and the marketing of consumer products containing recycled material have become areas of rapid growth within the last two years. As indicated in Table 25.7, this volume is growing rapidly. For recycling to work, someone must "close the loop" — that means there must be a demand for products made of recycled material. In addition, products labelled as "containing recycled material" sometimes do not include any postconsumer waste, only recycled material from industry that has never been part of the municipal solid waste stream. Products containing postconsumer recycled material are the ones that are "closing the loop" and reducing the landfilling of waste from homes and institutions.

During the late 1980s, the total quantity of waste going to landfill continued to increase on a year-to-year basis for all Canadian municipalities for which data are available (Federation of Canadian Municipalities 1990). Existing recycling systems have not achieved a major reduction in landfilling of waste, although a 1990 survey of 55 municipalities conducted for the Federation of Canadian Municipalities (1990) indicated that at least 70% of municipalities in all regions of Canada at least have recycling depots to which residents can take some types of waste material.

Composting

Composting means taking organic refuse (e.g., food wastes, leaves, and grass clippings) and handling them in such a way that naturally occurring bacteria and other microorganisms will break them down and produce a safe, clean, soil-like material called compost. It can occur in the presence of air (aerobic) or in a closed container or underground (anaerobic). Composting replicates the systems used in nature to get rid of biodegradable garbage: insects, earthworms, fungi, bacteria, and other living organisms break down dead plant and animal matter and turn it back into soil.

Refuse can be composted in the backyard or schoolyard, or composting can be done on a large scale in a central facility. Enthusiasts do it on apartment balconies and in worm bins in the kitchen. Wherever it is done, if it is kept free of contaminants and toxic chemicals, composting produces a material that is excellent for restoring organic content to agricultural and horticultural soils.

Several municipalities are currently implementing programs in which specially designed bins are provided at no cost or low cost to householders for backyard composting of grass clippings, leaves, other yard wastes, and kitchen wastes. In Ontario, over 30 000 units were distributed in 1990. A few are developing municipal-scale composting programs, through which these wastes will be collected from homes in specially designed containers and composted in a municipal facility. Several private operators already run large-scale composting facilities, generally for dealing with wastes from the food-processing industry. It has been estimated that composting has the theoretical potential to reduce the quantity of waste going for disposal by more than 30%.

Resource recovery

Resource recovery means the extraction of economically worthwhile components from the waste stream. Hence, it includes recovery of material through recycling, recovery of energy from landfill gas, and recovery of energy from waste. The term "resource recovery" is often used to describe recovery of energy from waste plants.

Modern waste plants have the ability to recover much of the energy and heat value that go into the manufacture of goods. Plastics, for example, are often made from natural gas, and much energy goes into their manufacture. By burning the waste plastic, the energy is obtained from the natural gas that originally went into the plastic. Much of the energy that went into its manufacture can be recovered as well.

Few new resource recovery plants are planned at present, although some municipalities are exploring the option of burning waste and recovering the energy produced. In addition, some industries are incinerating their own wastes, and selected clean scrap from other nearby industries, to recover the energy value. As energy costs rise, interest is being rekindled in recovery of the materials in the waste stream with high energy value (primarily paper fibre, plastics, and wood) to produce "refuse-derived fuel" (RDF) as an alternative fuel for solid fuel boilers.

Household hazardous waste

Quebec's inquiry into hazardous waste estimated that a "typical" consumer produces about 2.5 kg of household hazardous waste each year (Commission d'enquête sur les déchets dangereux 1990). Increasing concern is being expressed about the environmental impact of hazardous materials that find their way into landfill. It is almost inevitable, where landfills are unlined, that these materials will eventually leach out of the landfill site and contaminate surface water or groundwater, and that other hazardous materials will be carried out of the site as part of the landfill gas. In contrast, some observers have reported that the contents of lined landfills are, in essence, mummified, except for a slow degradation of food and plant wastes (Rathje 1989), and that this is perhaps a good thing from the point of view of leaching of toxic substances.

Until recently, individuals who wished to dispose safely of hazardous household products, such as unwanted fuels, were on their own. Today, municipalities are stepping in and providing systems of various kinds to collect hazardous wastes separately from the municipal solid waste stream. In some communities, special waste days are held. During these days, residents can take small quantities of hazardous wastes to a special temporary depot. In a few cases, these depots are permanent and open year-round. At the depot, the wastes are poured into drums containing wastes of like kind; subsequently, these drums are removed for proper treatment in industrial waste treatment facilities that are capable of handling waste of each specific type. In southern Ontario's Durham region, residents can call a "toxic taxi," which will visit their homes to pick up small quantities of hazardous waste and remove them for safe treatment.

Identifying household hazardous waste can be difficult. Product labels do not list all ingredients or ingredient concentrations. Nor is there a legal definition of household hazardous waste in Canada. If the product bears a warning such as "corrosive," "toxic," "reactive," or "flammable," it should probably be disposed of as hazardous waste if not completely used up for the purpose for which it was bought, but not all products that pose a hazard if they end up in municipal landfills are so labelled.

Some examples of ingredients that, depending on their concentration in the product, may cause problems in the municipal solid waste stream are heavy metals, toxic organic compounds, and chlorine. These ingredients show up in a variety of common household goods. Lead, which is a heavy metal, may be used in electronic components, automobile batteries, inks, and plastics. Organic chemicals, such as benzene, methylene chloride, toluene, and ethylene dichloride, are sometimes ingredients in household spot removers, automobile lubricating oils, latex paint, glues, and nail polish. Ordinary chlorine bleach is a hazardous household waste, as are products that contain chlorine, because of chlorine's strong ability to oxidize materials with which it comes in contact.

Other common household hazardous wastes include tile cleaners, carpet shampoos, used or unused oils and fuels, all batteries (from motor vehicle batteries to "AAA" cell batteries with reduced mercury content), turpentine, paints and stains, wood preservatives, pesticides, drain openers, rat poison, some pet care products, some cosmetics, pool chemicals, and ammonia. Although not a hazardous waste, a high-profile waste that can create serious problems in landfills and that enters the waste stream from households as well as from all other sectors is scrap tires (see Box 25.3).

Some pharmacists are working with consumers to keep pharmaceutical products out of landfills. Under a program operating in some areas, unused prescription drugs can be returned to a pharmacy. They will then be sent for incineration or proper disposal along with waste drugs collected from other consumers and from the pharmacist's own operations.

Many households are discovering less hazardous alternatives to the products they are using, reducing the hazardous waste both at home and at the manufacturing plant.

Landfill innovations

However much we might try to use other methods, there will always be a small percentage of the total waste stream that has to go to a disposal facility. Some estimates suggest that this should be no more than 20% of the amount that is currently landfilled. This residual waste would consist of nonrecyclable noncombustible materials such as building rubble and incinerator ash. It may also include small volumes of material that is so mixed with contaminants that technology to separate and recycle it does not exist.

Several landfill techniques are now in use or being developed for long-term safe storage of this material. The "engineered landfill" is designed with synthetic and/or clay liners all around the waste. Leachate and landfill gas collection systems inside the liners help ensure that the landfill is as leakproof as it is humanly possible to make it. Engineered landfills are able to completely contain their wastes for at least 25 years (G. Ferraro, Conestoga-Rovers and Associates, personal communication).

Another landfill innovation is the "retrievable storage" facility. This is designed on the assumption that one day in the future we will be able to treat wastes for which no safe treatment system exists today. These facilities may be above or below ground, as long as they are secure, and are designed somewhat like a warehouse so that the wastes can be removed at some time in the future. Although both engineered landfills and retrievable storage facilities were originally designed for hazardous industrial wastes, they are now being considered for municipal solid waste as well. Almost every urban

Scrap tires

Since a tire fire burned out of control for a month at Hagersville, Ontario, in February 1990, triggering the evacuation of hundreds of area residents, few Canadians remain unaware of the need to promote alternatives to tire dumps. When large stockpiles of used tires are ignited, they burn fiercely, producing fumes containing toxic substances, such as benzene and toluene; in the intense heat that is generated, other tires melt into an oily substance that can flow into water bodies or seep into the ground.

The number of car and truck tires discarded in Canada each year is estimated at 19.5 million. More than half (62%) of these are at landfill sites, either mixed into the actual landfill — where an (unshredded) tire takes up a lot of room for its mass and where it may, because it contains trapped air, "float" in the landfill and reappear at the surface — or simply stacked at recognized sites. Another 14% are stockpiled in unsightly and environmentally unsafe storage compounds; about 18% are reused or recycled each year; and the remaining 6% are burned, mostly in British Columbia and Prince Edward Island, to produce energy (e.g., as a fuel supplement in cement kilns or to generate electricity).

About 18.5 million used tires were stockpiled in heavily populated regions of Canada in 1990. Although the fire at Hagersville depleted the number of used tires in Ontario by 11.5 million, the province was left with 3.5 million tires in 60 sites. Quebec, even after a fire at Saint-Amable, retained 12.5 million discarded tires at 120 sites. British Columbia and Alberta have stockpiles of 0.5 million and 1.5 million, respectively. The other provinces have smaller or no stockpiles.

Various initiatives are under way to encourage reuse and recycling and to reduce reliance on storage and disposal. In addition to various provincial programs, there are the Canadian Council of Ministers of the Environment's Working Group on Used Tires and the Western Canada Scrap Tire Task Force.

Alternatives to stockpiling or landfilling used tires were current long before television broadcast images of the billowing black smoke at Hagersville around the world. Not only have whole tires been retreaded, they have been used as landscape borders, highway barriers, and artificial reefs. Tires have also been broken into small fragments known as crumb rubber and used for consumer products, such as carpet backing, or mixed into asphalt. Used tires can be processed into tire-derived fuel or pyrolyzed to produce oil and carbon black. Unfortunately, these and other alternatives to stockpiling have not thus far been able to absorb all the scrap tires that Canadians generate. In keeping with the 4 Rs of waste management, Canadians are taking a fresh look at the question of scrap tires.

Source: CCME (1990).

landfill designed today is engineered in some way to contain wastes.

New techniques are also being applied to the siting of landfills. No longer is waste piled into abandoned quarries or marshland. Today, siting studies identify a number of locations that may be environmentally appropriate for landfilling. Detailed tests are done on each site to ensure that an adequate impermeable layer underlies it. Studies also look at possible air pollution effects, impact on the local community, relationship of the site to community facilities, seniors' homes, schools, cemeteries, historic and cultural features, sensitive flora and fauna, and much more. Only after all these possible environmental impacts have been measured is the final site chosen. Even after all these studies, the people in most communities still oppose any landfill or waste management facility in their neighbourhood. Experts have coined the term "not in my back yard," or NIMBY, syndrome to describe this local opposition to activities or facilities imposed by the larger community.

Integrated waste management

"Integrated waste management" is a term used to describe either a hierarchy of waste management options — reduction, reuse, recycling, resource recovery, and landfill — or a planning process that looks at the entire concept of waste rather than at individual components of a system such as landfill or incineration. Today, many municipalities in Canada are developing waste management master plans: comprehensive overviews of the approach to waste that the municipality intends to take during the next 10 or 20 years. These integrated approaches generally give priority to source reduction, reuse, recycling, and composting options, while also including facilities for energy-from-waste and landfilling of residues.

The evolution of a waste management system primarily dependent on landfilling is largely the result of ignoring the true benefits to society as a whole associated with managing wastes in an environmentally sound manner. The most promising trend to reverse the established practice of relying on landfilling of wastes is the move towards establishing true cost accounting for our waste management systems. Some communities in Canada are reducing the frequency of waste collection service in order to increase cost savings and to encourage reduction. These practices must lead to better understanding of the wastes we produce and increased focus on all strategies for reduction.

CONCLUSION

Waste is a by-product of our present economy — an economy that was built in large measure on the inexpensive and rapid exploitation of Canada's natural resource base, without accounting for environmental consequences, including waste management costs and the value of the resources wasted. The ambitious waste reduction targets that have been established in several provinces, and by the Canadian Council of Ministers of the Environment, confront our basic economic structures and premises directly, along with all of the poor decisions we have grown to accept as a consumer society. It will require a sincere reexamination not only of how we manage our wastes in the future, but also of the systems we use for production and the values that drive our consumption.

The paucity of data in this chapter is a symptom of the "out of sight, out of mind" attitude that we have had towards waste management in Canada. Not only have we tried to forget about the garbage, but we have also not systematically collected data on the amount of it that we produce or the methods that we use to manage it. The National Task Force on Packaging has established a data management system that will track packaging waste (see Box 25.2). A similar system for total waste generation and composition would help reduce waste by 50%, from the 1988 rate of about 1.8 kg per person per day, by the end of the century.

Many provinces and municipalities are just beginning to set up programs to reduce waste and increase recycling. Although few data were available for inclusion in this report, every indication is that landfilling of waste could decrease in every part of Canada by at least 25% by 1995. Not only will the next five years see major changes, but perhaps there will also be data to show how much we have achieved and how far there is yet to go.

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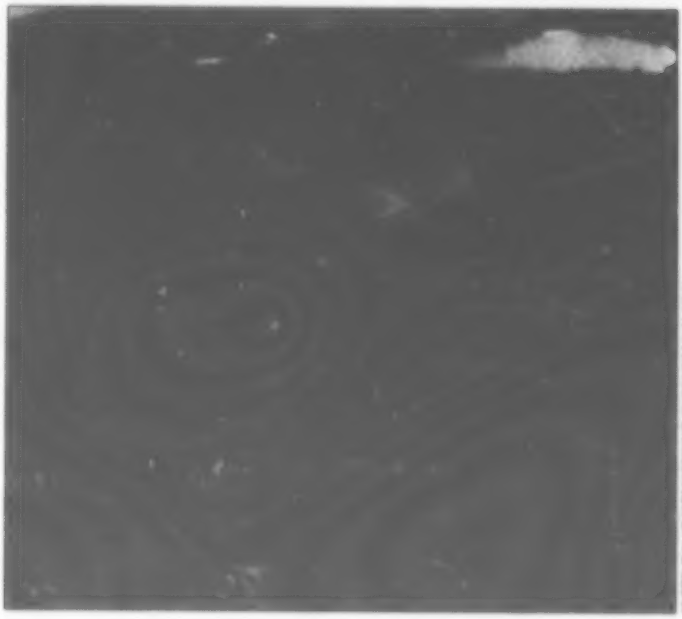

HIGHLIGHTS

Without habitat, there is no wildlife. However, the habitat for many of Canada's wild animals and plants is threatened by various human activities.

■

About 1 million hectares of Canada's forests are logged annually; after planting, reseeding, and natural revegetation, 18–25% remains without trees, with a consequent temporary loss of habitat for forest species. Of particular concern is old-growth forest habitats.

■

The quadrupling of Canada's agricultural land since the early 1900s has led to fragmentation of habitats: across the prairies, more than 75% of the natural grassland and aspen parkland habitat has been converted to cropland. In several parts of southern Canada, more than 70% of all wetland habitats have been lost, with agriculture being blamed for 85% of the losses.

■

Habitats are also lost or degraded by urbanization, hydrocarbon spills, industrial and municipal developments and effluents, and hydroelectric developments. Pollutants that cause acidic deposition are damaging the habitats of aquatic wildlife, while those that cause climatic change are threatening stability of all ecosystems.

■

Canada is increasingly using a two-pronged approach to habitat conservation:

– a landscape approach, which provides for ecologically sound use of resources as well as environmental protection of all Canadian landscapes

– a national network of representative protected areas, within a landscape approach.

■

More sustainable forestry practices, conservation agriculture, reductions in contaminants, and land stewardship programs are helping to reduce stresses on wildlife habitats. More area is protected by parks, ecological reserves, and other designations. The $1.5-billion, 15-year North American Waterfowl Management Plan, the Permanent Cover Program that encourages conversion of marginal agricultural lands on the prairies to forage and habitat, 100 Migratory Bird Sanctuaries, 45 National Wildlife Areas, the Western Hemisphere Shorebird Reserve Network, and the Endangered Spaces Campaign are among the many programs that aim to protect and restore habitats.

■

If sound management policies are to be devised, then a crucial current priority is the gathering and analysis of far more ecological data than we now possess.

■

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> “Even the most urban-oriented person... needs a constant, available supply of uncontaminated water, clean air, food... and space to live in relative comfort, safety, and harmony. Although people may not think of these needs as “human habitat,” those elements still are the basic requirements of our lives.... The lands and waters that produce virtually all human needs also harbour most of our wildlife. And their capability to support fish, birds, and mammals is a good indicator of their capacity to meet the basic needs of man.”
>
> — Wildlife Management Institute (1987)

INTRODUCTION

Wildlife is at once producer and product of its environment. No plant or animal can survive without adequate supplies of food and water and an appropriate space in which to live — in short, adequate habitat. While many Canadians value wildlife highly and are greatly interested in it, few really appreciate the complex and dynamic interdependence of organisms and their habitat. Attention can be focused on fragmentary details, rather than on the whole ecological picture. For example, the pros and cons of shooting waterfowl are widely debated; the widespread practice of draining the wetlands on which the same waterfowl depend for nesting and staging habitat frequently goes unnoticed.

Wildlife provides a wide variety of social, economic, and ecological benefits to Canadians (see Chapter 6). Canada is home to more than 72 000 species of wild plants and animals (see Table 6.1), an exceptional biological diversity. Unfortunately, the future habitat supply for many species is far from secure. As of 1991, 193 species had been formally recognized as endangered, threatened, or vulnerable (see Tables 6.2 and 6.5), most frequently because of loss or degradation of vital habitat. It is becoming ever more important to sustain adequate habitat if Canada is to maintain its biological diversity.

PRESSURES ON WILDLIFE HABITAT

Pressures on wildlife habitat can be reflected in the changing abundance, distribution, and diversity of particular habitats; measurements can be made in terms of habitat quality as well as quantity. The pressures can be exerted by natural phenomena, such as forest fires, extreme weather events, and landslides, or they may result, either directly or indirectly, from various human activities. This chapter primarily examines those pressures that result from human activity.

Forestry

The forest industry is the largest single, sectoral contributor to Canada's economy (see Chapter 10). For this reason, it is vitally important that Canadians appreciate the relationship between the process of resource extraction that we call forestry and the complex natural community that we call a forest.

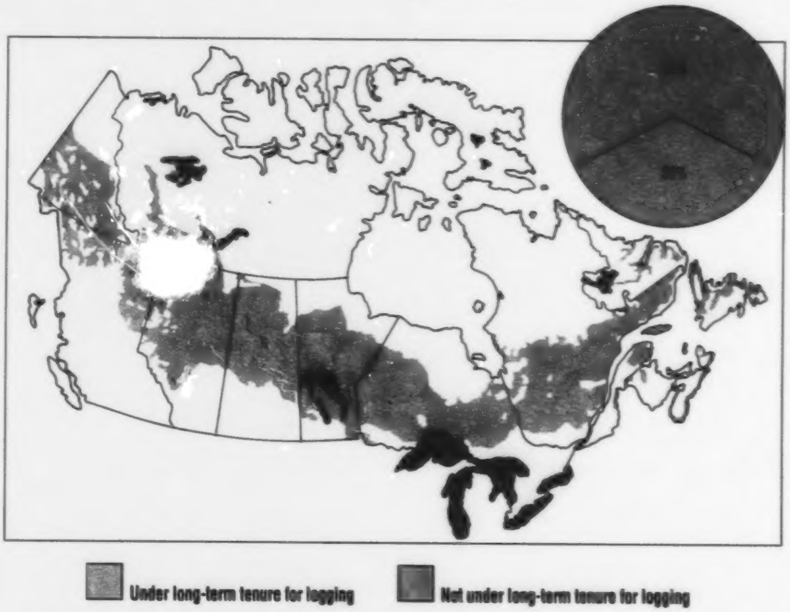
Canada's forest ecosystems sustain a great diversity of habitats for tens of thousands of plant and animal species. To guarantee the sustainability of forest habitats, forest management techniques must recognize the ecological parameters of each site. To give a single example, slopes that are unprotected by forest cover can be especially vulnerable to soil erosion and nutrient leaching. Clear-cut logging, which often may be the most efficient method of harvesting wood fibre, can leave forest lands open to erosion. This can lead to siltation, which adds excess nutrients to stream and lake habitats and also causes a higher incidence of landslides, which block streams and damage aquatic habitats.

Canada's forests cover an area of nearly 453 million hectares, or about 45% of the total Canadian land area. Approximately 244 million hectares are productive for wood products (Forestry Canada 1991). From 1986 to 1988, an average of slightly more than 1 million hectares of forest was logged each year. Of this total, only 299 518 ha were replanted in 1986, 370 245 ha in 1987, and 413 291 ha in 1988 (Forestry Canada and Canadian Pulp and Paper Association 1990). An additional 26 000 – 38 000 ha were seeded directly, and 400 000–450 000 ha underwent natural regeneration (Forestry Canada and Canadian Pulp and Paper Association 1990). In all years prior to 1988, less than 75% of the area that was logged was successfully regenerated (Indicators Task Force 1991). From a tree-planting perspective, this situation has been improving: in 1988, about 82% of the area cut was successfully regenerated (Forestry

FIGURE 26.1

Boreal forest currently under long-term tenure for logging

Boreal forests cover 34% of Canada. Approximately half are productive for wood products.


Under long-term tenure for logging
Not under long-term tenure for logging

Source: McLaren (1990).

Canada 1991). From an ecological perspective, however, both the amount of reforestation activity and the techniques that are used have significant implications for the survival of forest wildlife.

Forest management techniques that are compatible with the needs of wildlife will retain a mix of remnant forest patches and will permit only selective logging in sensitive areas. Forests must also contain a variety of successional stages suitable for different species of wildlife and travel corridors to provide highly mobile animal species with access to areas of undisturbed habitat. This style of forest management accepts as one of its goals the provision of a broad range of food, shelter, and other habitat conditions for native wildlife species.

A certain proportion of clear-cutting can be appropriate if it is interspersed with other logging practices. Moose, deer, and elk, for example, may benefit from the forage that develops along the edge of clear-cuts; yet they also require dense forest nearby for shelter. Woodland caribou, on the other hand, prefer older stands of evergreens, which provide abundant lichens for food. Large clear-cuts can isolate caribou from important parts of their range.

Too often, in the interests of efficient harvesting, clear-cut areas are replanted with a single species of tree rather than a variety of tree species. Monoculture stands of the commercially preferred evergreens are planted at the expense of deciduous trees, and habitat diversity is reduced. In the face of such radical alteration of habitat, some species may become locally extirpated.

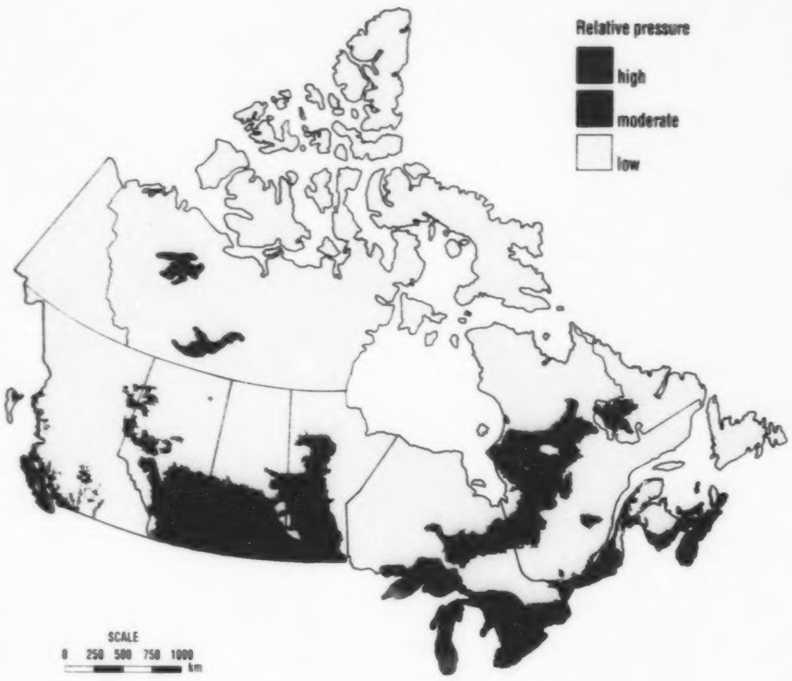
Even when forest management takes wildlife values into account, it can focus exclusively on game species. Deer, elk, or moose are often used as indicators of forest health, on the assumption that conditions that benefit them will benefit all wildlife. This is not necessarily true. While deer and moose may thrive in areas that have been cut recently, other species such as grizzly bears, marten, woodland caribou, and eagles all rely on later successional stages with different habitat qualities. Thus, land that is managed in the interest of only a few species may be rendered uninhabitable to other wildlife.

The progressive disappearance of certain types of old-growth forests in recent years has generated much interest and some confrontation. In several regions, timber shortages and the high profits that the forest industry can realize from old-growth timber are increasing the pressure to log these remnant forests. In recent years, industry, government, and environmental groups have expressed conflicting views, particularly over "hot spots" such as the Temagami forest in Ontario, and Lyell Island and the Carmanah, Stein, and Khutzeymateen valleys in British Columbia. Old-growth forests provide critical habitat for a number of wildlife species, like the endangered Spotted Owl and the threatened Marbled Murrelet. For both species, dead, standing trees, or snags, which are common in old-growth stands, are especially important as nest sites. In British Columbia, 79 vertebrate species are believed to depend, partially or entirely, on old-growth forests (British Columbia Ministry of Environment 1989). However, only about 9.3% of the old-growth forest of British Columbia remains (Foster 1989).

Boreal forest (Fig. 26.1) covers 34% of Canada. It is largely an evergreen forest dominated by spruce, fir, and pine, with poplar and birch the prevalent deciduous trees. Roughly 65% of Canada's boreal forest is currently under long-term tenure for logging (Fig. 26.1). This represents almost all of the country's most productive boreal forest and includes several provincial parks and wildlife reserves (McLaren 1990). Serious concerns have been expressed about how forestry activities affect boreal

FIGURE 26.2

Land-use pressure on Canada's wetlands



Source: Rubec (1990).

forest habitats. In Alberta, for instance, about 100 plant species are found only in the boreal forest, and this forest type is also the only nesting habitat of dozens of warblers and other forest songbirds that summer in Canada (McLaren 1990).

Besides altering forest plant and animal communities, logging operations open vast areas of forest to other traffic. In Manitoba, for example, current logging plans include the construction of 2 000 km of bush roads (McLaren 1990). Roads invite expansion of industrial and recreational activities into hitherto isolated areas, often making the favourable habitat created by logging unavailable to many game species through ongoing harassment and excessive hunting. Road construction can also contribute to the siltation of rivers and the degradation of fish habitat.

Agriculture

The amount of land devoted to agriculture in Canada has quadrupled since the early 1900s (Girt 1990), with natural forest, wetland, and prairie habitats being converted to expanses of intensively used croplands and rangelands. Initially, on a limited scale, such conversions enriched biological and habitat diversity, actually providing opportunities for some species, such as the Greater Prairie-Chicken, to expand their original range quite extensively. After World War II, however, strong international demand for food production and improvements in agricultural technology resulted in a rapid expansion of agriculture. The remaining areas of untouched wildlife habitat became progressively more fragmented, more isolated, and often too small to sustain viable populations of species that had once been abundant. Under the pressure of diminishing habitat, wildlife species become more susceptible to the stresses of disease, drought, predation, and human presence. Isolation effectively prevented immigration from other areas to restock depleted populations, and, in some instances, local extirpations occurred (Thompson 1987).

Until very recently, prairie farmers had many incentives to expand cropland and few to conserve wildlife habitat. The *Canadian Wheat Board Act* set grain delivery quotas that were based on the total area seeded and in summer-fallow. This system encouraged farmers to maximize the areas in crop production, cultivating land that would otherwise be economically marginal, rather than managing their land based on its productivity. It was financially attractive for farmers to drain wetlands, clear treed streambanks, and remove shelterbelts to increase the area under production (Alberta Water Resources Commission 1990). The policy has been under review since 1987 and may be changed from an area-based delivery quota system to volume-based delivery.

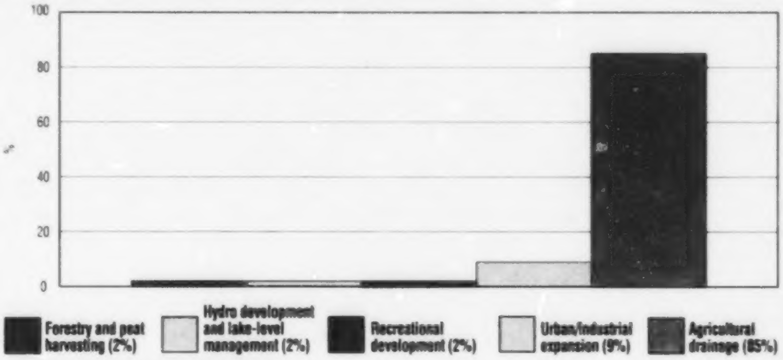
In western Canada, less than 1% of the original tall-grass prairie currently exists. While other prairie landscapes have suffered less, only 18% of the formerly abundant short-grass prairie, 24% of the mixed-grass, and 25% of the aspen parkland remain (Gauthier and Henry 1989). Thus, prairie wildlife species that depended on these native habitat types must now subsist on one-quarter or less of their original habitat. In Saskatchewan, a survey of 25 municipalities covering 1976–85 showed native habitat disappearing at an average rate of 1.2% per year (Weins 1990). As of 1986, 75.4% of the 27 million hectares of land lying south of Saskatchewan's provincial forest had been converted to agricultural uses. Between 1980 and 1990, 38.9% of aspen parkland habitat was lost in an 800 000-ha study area in southeast Saskatchewan (Weins 1990). In the Peace River region of Alberta, about 36 000 ha (0.81%) of the forested land is cleared annually, mainly for agriculture (see Box 5.1). In many of these conversions, important wildlife habitat is sacrificed at the expense of marginally productive farmland. For example, only 3.5% of the land in the Peace River study area had a high capability for waterfowl; yet, of that small amount, about 43% had been converted to cropland by 1986, and another 24% is threatened with eventual agricultural development.

Ecologically speaking, wetlands are among the world's most important landscapes. Shallow open water, fresh and salt marshes, and other types of wetlands provide critical nesting and feeding habitats for birds and spawning and nursery grounds for fish and shellfish. Nationally, more than 155 species of birds, 50 species of mammals, and an extensive variety of plants depend on wetlands (Rubec *et al.* 1988). They are the preferred or required habitat for about one-third of the wildlife species identified as endangered, threatened, or vulnerable by the Committee on the Status of Endangered Wildlife in Canada (Federation of Ontario Naturalists and Environment Canada 1987). In Ontario, this proportion rises to 86%, as 12 of Ontario's endangered species depend on wetlands (Soil Conservation Society of America 1987).

Wetlands currently cover 14% of Canada's surface area, a total of 127 million hectares (Environment Canada 1986), representing nearly one-quarter of the world's wetlands. Since European settlement, however, 80% of wetlands in the Fraser River delta in British Columbia, 71% of prairie wetlands, 70% of southern Ontario wetlands, and 65% of Atlantic coastal marshes have been lost, mainly due to agricultural expansion (Environment Canada 1986). An estimated 0.5% of Alberta's wetlands continue to disappear annually due to agricultural drainage (Alberta Water Resources Commission 1990). Figure 26.2 illustrates areas in Canada where pressures on wetlands are felt to be highest, and the strong correlation with the country's principal agricultural areas is evident.

FIGURE 26.3

Causes of wetland loss in Canada south of 60°N



Unknowns: Climatic change, pollution/acid rain

Source: Clarke *et al.* (1989).

Conversion to agricultural uses has been blamed for 85% of Canada's wetland losses (Fig. 26.3). The health and sustainability of the remaining wetlands in the areas of high pressure are in doubt. Intensive agriculture can lead to soil erosion, and hence siltation within wetlands, as well as degradation of water quality due to runoff of fertilizers, pesticides, and salts leached from soil. On average, across the prairies, 60% or more of wetland basins and 80% of the habitat surrounding these basins are affected by farming each year, often with significant impacts on waterfowl (Turner *et al.* 1987).

Eroded soils and fertilizers and pesticides leached from fields also degrade other types of wildlife habitat. Wind and water erode more than 277 million tonnes of soil from farm fields annually (Hoechst Canada Inc. 1984). Ontario farms contribute more than 1 million tonnes of sediment to the Great Lakes each year (Algie 1988), smothering fish spawning grounds and destroying the aquatic organisms on which fish feed. Fertilizer use in Canada has increased by 250% since 1960, while pesticide use has climbed by 300% (Girt 1990). The improper use of fertilizers and pesticides can damage habitats and even destroy soil microorganisms such as the fungi and bacteria that help bind the soil together. As these microorganisms die off, the soil becomes more susceptible to wind and water erosion. Leaching of fertilizer contributes phosphorus and other nutrients to the water. In the Great Lakes basin, agricultural land is responsible for 60–70% of all sediments and 50% of the phosphorus reaching water bodies (Nowland and Halstead 1986). These chemicals also taint coastal habitats. In 1988, fertilizer and pesticide pollution was responsible for the closure of shellfish harvesting on over 500 ha of intertidal zone on the west coast (Kay 1989).

Urban and industrial development

Of all the human pressures that alter native ecosystems, some of the most profound stem from the growth and development of urban and industrial centres. Ranging from simple occupation of territory to the complex side-effects of activities at these centres, their collective impact on natural communities can be enormous.

Population growth

In keeping with worldwide trends, Canada's human population is expanding dramatically. It rose by 72% between 1951 and 1986 (Greenprint for Canada Committee 1989), and it is expected to approach 30 million by the year 2000. Hand-in-hand with increased population comes the expectation of greater economic prosperity, placing unaccustomed pressures on wildlife habitat. The past four decades have seen a marked shift of residence from rural to urban communities (see Chapters 5 and 13). By 1986, 76.5% of the total population lived in urban centres with more than 1 000 people (see Table 13.2). As urban centres grow in population, they also expand outwards onto rural lands. Between 1981 and 1986, for example, about 55 200 ha of rural land were converted to urban uses by 70 selected Canadian cities with populations over 25 000 (Warren *et al.* 1989). This kind of conversion generally results in a decline in the quantity and quality of wildlife habitat.

Recent data on the conversion of high-quality sites to urban uses are not available, but a look at past trends provides a general perspective for this issue. For example, between 1966 and 1976, 76 000 ha of high-capability land for ungulates and 11 000 ha of high-capability land for waterfowl were converted to urban uses in all 80 urban centres in Canada with populations of over 25 000 (Warren and Rump 1981). Shopping malls, industrial parks, and business cores provide habitat for only a handful of the most adaptable species of wildlife. Urban habitats tend to be low in biological diversity. Nonetheless, songbirds, squirrels, raccoons, and other species that do occupy urban habitats, such as inner-city parks, backyards, tree-lined streets, river gullies, and vacant lots, often occur in significant numbers.

Introduction of exotic species

A subtle yet insidious form of habitat change occurs through the accidental or intentional introduction of exotic, or nonnative, plant and animal species. Such introductions can occur in all kinds of habitat and can result from many kinds of human activities, as well as by natural means. However, they are most commonly associated with urban and surrounding agricultural landscapes, where imported plants or animals have escaped from gardens, fields, or cages and have invaded natural habitats.

Besides competing with and displacing native species, thus diminishing Canada's native biological diversity, exotics can sometimes dramatically alter whole ecosystems. An impressive example is the rapid spread of purple loosestrife throughout much of southern Canada (Environment Canada 1991). In recent years, this plant has invaded wetlands in every province, with extensive infestations occurring in southern Quebec, Ontario, and Manitoba. It develops dense single-species stands from which native plants and animals are virtually excluded. Its many reproductive options, including heavy seeding, seed longevity, root sprouts, vegetative reproduction, and an ability to grow in a variety of habitat conditions, have enabled purple loosestrife to dominate the sites that it invades. A strikingly attractive flower head has made this exotic a popular garden perennial, facilitating its spread across Canada. Of particular concern is the rate at which it infills wetlands, reducing their productivity, excluding the presence of native species, and adding additional pressures to already-threatened wetland communities. Governments have recognized and are working on this problem, but solutions have been hard to find. Several other exotic plants, including flowering rush,

Purple loosestrife in wetland.

Photo courtesy of G. Lee, Canadian Wildlife Service, Ottawa.

phragmites, and Eurasian-water milfoil, are also degrading native wetlands. Effective controls and eradication techniques have yet to be found for occurrences like these, but strategies to deal with them are needed if their effects are to be reduced or eliminated.

Mining and energy

The mining industry contributes significantly to the Canadian economy (see Chapter 11), but the economic benefits do not come without environmental costs. Not only do tailings ponds, waste rock dumps, open pits, and other surface disturbances impact on wildlife habitat, but mining also leads to extensions of roads and settlements into increasingly remote locations, posing an ever-greater threat to Canada's wilderness habitats. However, it would be unjust to paint an entirely negative picture. The successful rehabilitation of abandoned coal mine sites, as demonstrated at some locations in Alberta and British Columbia (see Chapter 11), offers the possibility of creating productive oases for wildlife.

Mining and energy developments in remote areas usually require roads and transmission corridors (e.g., for pipelines and electrical lines), which increase human access to wildlife habitats. Construction of roads and wells near Manyberries, Alberta, for example, has resulted in the direct loss of critical habitat for Sage Grouse and mule deer. Between 1980 and 1983, Sage Grouse populations declined twice as quickly in this area as in less disturbed, outlying habitats (McCulley 1983).

Hydroelectric developments influence ecosystems both upstream and downstream from a dam. Box 26.1 summarizes a few of the types of habitat alterations that the quest for energy can impose.

Petroleum and natural gas developments can also damage aquatic ecosystems. Since 1986, initiatives such as Hibernia, Other Six Leases Operation (OSLO), and the planned development of the Beaufort Sea gas fields have generated considerable public concern, especially about the risk of habitat degradation by oil spills. In 1988, for example, the sea-going barge *Nestucca* spilled 875 000 L of oil in waters just south of Vancouver Island. Coastal habitat was affected along 150 km of coastline, including Pacific Rim National Park and six provincial ecological reserves (Kay 1989). Canadian marine ecosystems are subject to about 100 small spills, 10 moderate spills, and at least 1 major spill every year, while a catastrophic spill (more than 10 000 t) is probable about once every 15 years (Public Review Panel on Tanker Safety and Marine Spills Response Capability 1990). Important freshwater habitats, notably in the Great Lakes/St. Lawrence waterway, are also threatened by potential spills from tanker traffic (Fig. 26.4).

Contamination of aquatic habitats

Contamination by sewage and industrial wastes poses a special threat to aquatic ecosystems. In some areas, especially along Canada's heavily populated southern fringe, streams and lakes are so contaminated that they can no longer sustain traditional communities of plants and animals. Municipal sewage systems are major culprits in this regard. Although most Canadian communities of more than 1 000 people are now served at least by primary sewage treatment plants, the effluent sewage is still generally discharged to rivers, lakes, or marine estuaries, loaded with heavy metals, nutrients, and suspended organic solids (Indicators Task Force 1991).

The principal aquatic habitats in the Great Lakes basin exhibit high levels of a great variety of contaminants (see Chapter 18). Some 43 areas of particular concern have been identified in this basin (see Fig. 18.13). Contamination is so severe in 38 of these areas that the human consumption of fish taken from their waters is restricted. Dredging activities are restricted in 31 areas due to high levels of toxic contaminants in bottom sediments (Hartig and Hartig 1990).

Along the Pacific coast, officially authorized waste disposal is contaminating a growing amount of marine habitat. In 1988, the Government of British Columbia authorized 389 marine discharges, up from 82 in 1973 (Fig. 26.5). Municipal sewage, both treated and untreated, is the most common substance being discharged under such authorizations. It can lead to contamination of clams, oysters, mussels, and other filter feeders, which tend to concentrate bacteria and other contaminants in their tissues. Figure 26.6 shows the areas closed to shellfish harvesting because of bacterial contamination.

Other discharges can also be harmful. One coastal mine in British Columbia has dumped more than 40 000 t of tailings, waste rock, and other inorganic solids into the ocean, causing elevated levels of some trace metals in locations more than 27 km from the discharge point (Kay 1989). Industrial contamination of Pacific coast marine habitats is evident from high levels of chlorinated organics in the resident seabirds (Kay 1989). Prime sources of these contaminants are the coastal pulp and paper mills that discharge large volumes of wastewater into coastal waters. Levels of dioxins, furans, PCBs, and other persistent chlorinated organics tend to be highest in marine habitats near pulp mills.

Contaminants can be transported long distances by air and water, and they are now showing up in remote aquatic habitats of Canada's far north (see Chapter 15). For example, ocean currents are introducing pesticide residues from Asia into the arctic seas. Proposed new pulp mills in northern Alberta could lead to contaminants entering the Arctic by way of northerly flowing rivers.

Acidic deposition

An estimated 46% of the total area of Canada contains aquatic habitats that are sensitive to acidic deposition, frequently referred to as "acid rain" (see Chapter 24). The proportions are highest in Quebec (82%), Newfoundland (56%), and Nova Scotia (54%) (Environment Canada 1988; see also Fig. 24.8). Waters in the Canadian Shield and Atlantic Canada are particularly vulnerable, as the bedrock and soils of these areas have little capacity

BOX 26.1

Some effects of dams and reservoirs on wildlife habitats

The environmental impacts of dam construction and reservoir creation for hydroelectric generation, irrigation, and community consumption have aroused considerable concern in recent years. This is especially true for a number of megaprojects. As environmental impact assessments are a fairly recent legislated requirement, most dam and reservoir developments prior to the 1980s were completed without a comprehensive examination of their ecological effects. As such, we are only now beginning to understand many of their consequences. The following are some of the recognized changes in wildlife habitats as a result of dams and reservoirs.

- Hydroelectric dams reverse the natural pattern of river flow. Contrary to the previous natural regime, flow downstream of the dam is manipulated to become highest in the winter when energy demands are highest. It is reduced in the spring and summer, resulting in shoreline vegetation upstream becoming flooded during the time when waterfowl are most sensitive to the loss. At this time they require the vegetation for food as well as for nesting and brood-rearing cover. Flooded shorelines with fluctuating water levels offer low-quality nesting habitat, and substantially diminished breeding success has been demonstrated for some dams.

- Where tracts of forest and other terrestrial vegetation become submerged by reservoirs, the decaying plant matter consumes the dissolved oxygen in the water, creating oxygen-poor habitat conditions for fish and other aquatic organisms. The carbon dioxide released in the decay process fuels algal blooms.

- Mercury occurs naturally in bedrock and soils and is released slowly into the environment through weathering processes. Trees, shrubs, and other plants take up some of this mercury when they remove water from the soil. Throughout the life span of a plant, this mercury tends to accumulate in its tissues as methylmercury. Once submerged, the vegetation dies and begins to decay. As it decays, the methylmercury is released into the water, contaminating the whole aquatic habitat.

- Through bioaccumulation, aquatic organisms incorporate mercury in their tissues, and levels biomagnify up the food chains. Fish in some Canadian reservoirs have been found to have several times the normal levels of mercury in their tissues. There are potential health implications for species which eat large quantities of these fish, such as mink, otter, Osprey, Bald Eagle, and humans. In northern lakes and reservoirs, because of the typically low temperatures, the decomposition of organic matter is generally slow and thus elevated mercury levels are likely to persist for several decades.

- Restricting river flow results in the conversion of many downstream wetlands to less-productive terrestrial habitats. In addition, the restricted flow reduces the amount of sediment normally deposited in downstream delta ecosystems.

- Anadromous fish, such as salmon, migrate from salt water to fresh water to spawn. Dams can interrupt this migration, thus preventing the fish from reproducing. In other cases, the reservoirs cause direct disruption to the spawning habitat of such species.

- Some species of freshwater fish, such as lake whitefish, have been observed to migrate between water bodies for feeding, spawning, or overwintering. Dams that do not include fish passage facilities have led to dramatic declines of populations of fish species in some locales, with resultant impacts on commercial fisheries.

- Regardless of the ultimate purpose of the dam and reservoir, where water is diverted from one watershed to another, new species of fish and other wildlife may be introduced to the receiving watershed, placing possible stresses on native species.

- Downstream from dams in the prairies and Rocky Mountain foothills of western Canada there have been declines in poplar forest. The declines have been attributed to altered hydrological patterns which are unfavourable for seedling establishment and survival of mature trees.

- Some reservoirs become "traps" for toxic contaminants. For example, agricultural and forest lands treated with fertilizers and pesticides may, as a result of soil erosion, contribute contaminated sediments to the bottom of a reservoir.

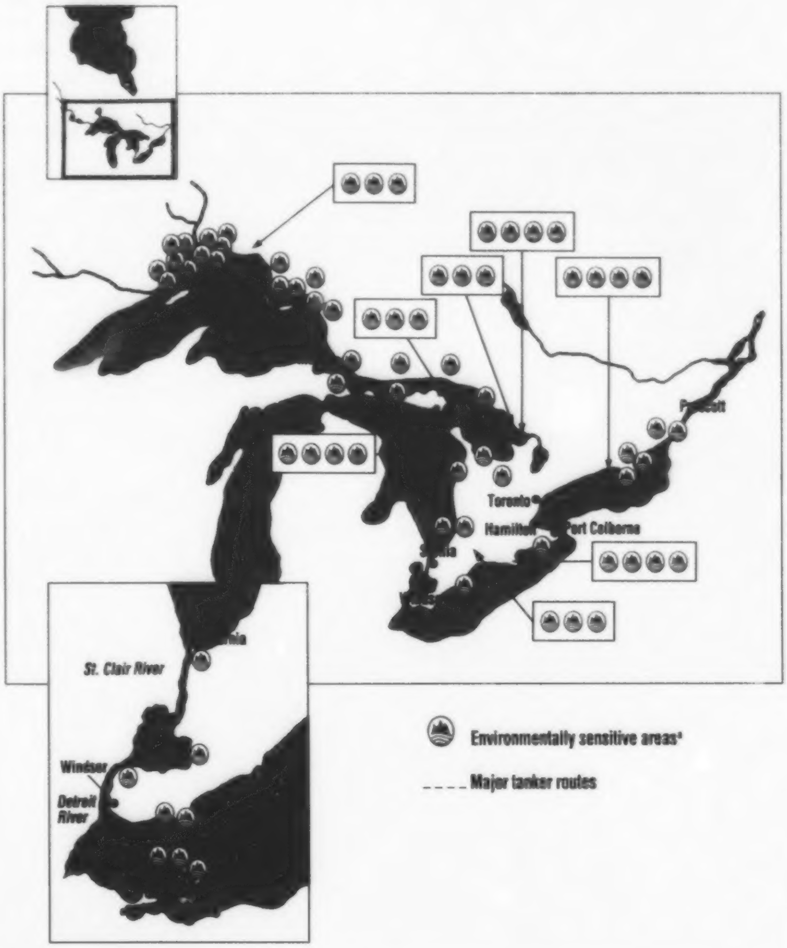
Source: Delisle and Bouchard (1990); Chapter 12.

to buffer any additional acidity. Some parts of southwestern British Columbia, the Prairie provinces, Yukon, and the Northwest Territories are also showing signs of acidification. Throughout the country, over 150 000 lakes are already suffering from acid damage, and more than 14 000 are considered "dead" (Government of Canada 1990).

Acidic deposition causes a reduction in the lake's natural pH level (i.e., an increase in acid content), bringing about immediate changes to aquatic habitats. The water chemistry changes, as does

FIGURE 26.4

Major tanker routes and important habitats in the Great Lakes system



^a Includes coastal and marine parks, wildlife sanctuaries, and conservation areas.
Source: Public Review Panel on Tanker Safety and Marine Spills Response Capability (1990).

the amount of dissolved oxygen in the water. Rocks become stained with algae, and quantities of invertebrates and other organisms are reduced because of an inability to reproduce (Fellman 1990). As the pH drops, this trend worsens. Few fish can reproduce, and the young that hatch soon starve due to the lack of invertebrate prey. In a study of 30 northwestern Ontario lakes where the pH was below 5.5, 20 were devoid of fish (McNicol *et al.* 1987). With the depletion of fish populations, Great Blue Herons, Bald Eagles, Kingfishers, Common Loons, Ospreys, and other fish-eating birds are also affected. Clams, crayfish, and snails, all of which have high levels of calcium in their shells, are also highly sensitive to acidity. So are the birds that feed on them, since the reduced availability of calcium from these prey species leads to thinner eggshells, which are more susceptible to breakage (Glooschenko *et al.* 1986). Acidic deposition can also contaminate aquatic habitats with mercury and other heavy metals, resulting in low waterfowl reproductive levels. A lake's ecological balance is the product of thousands of years of evolutionary processes. When organisms are extirpated, many do not return, even if the lake's natural acidity is restored by treatments with lime or by the reduction of the acidic deposition.

Of the water bodies in the Atlantic provinces, 120 000 (84%) in insular Newfoundland, 11 000 (86%) in Nova Scotia, and 10 000 (89%) in New Brunswick occur within areas of moderately high to high risk of acidification (Hélie 1991). These water bodies total 1.5 million hectares of potentially acidified surface water. In Prince Edward Island, some 1 100 water bodies, totalling nearly 2 200 ha, are all in areas of moderately high to high sensitivity, but most of them are well buffered due to the presence of carbonate-rich groundwater. More than 87% of all surface water bodies of the Atlantic provinces consist of lakes and ponds of less than 5 ha (Hélie 1991). These small water bodies often have relatively higher wildlife habitat values than larger water bodies.

Acidic deposition also affects forest ecosystems, leaching nutrients from soils and damaging foliage. This stresses the forest as a whole and is expected to contribute to changes in species composition of both floral and faunal communities. The leaching of metals from soils and their uptake into vegetation appear to be implicated in the high levels of cadmium found in the livers and kidneys of Labrador caribou and moose, as well as their poor state of health and the unpalatability of their internal organs to native people (V. Geist, University of Calgary, personal communication).

Climatic change

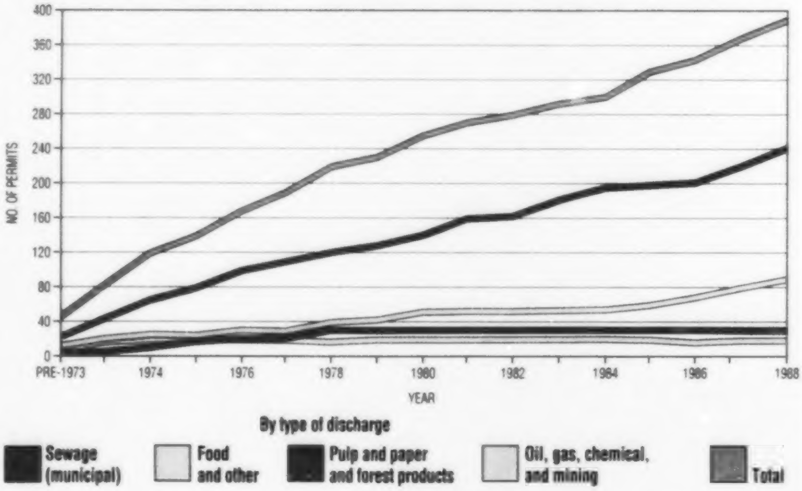
Global warming results from increased atmospheric concentrations of "greenhouse gases" — especially carbon dioxide — which trap heat within the atmosphere (see Chapter 22). The burning of fossil fuels discharges carbon dioxide into the atmosphere at a faster rate than natural processes can remove it. Meanwhile, logging and

Recreational activities can inadvertently result in damage to wildlife habitats.

Photo courtesy of National Film Board of Canada.

FIGURE 26.5

Number of permits issued by the Government of British Columbia authorizing the ongoing discharge of wastes into the Pacific Ocean



Source: Kay (1989).

other deforestation are removing trees, which are the Ecosphere's principal long-term storehouses of carbon. Since the mid-1800s, atmospheric carbon dioxide has increased by about 25% and global temperatures have increased by about 0.5°C (Anderson and Reid 1990). At current rates of emission for greenhouse gases, global mean temperatures are predicted to increase by about 0.3°C per decade during the next century (Intergovernmental Panel on Climate Change 1990).

Climatic change has the potential to dramatically alter entire ecosystems (see Figs. 26.7 and 22.10). The rate of warming in northern latitudes, for instance, could be twice the global average, causing a major reduction in the area of the arctic, subarctic, and boreal regions and greatly expanding the cool temperate, moderate temperate, and grassland regions (Rizzo and Wiken 1989). These changes will be accompanied by dramatic shifts in energy and moisture balances, productivity rates, and the basic character of habitats within each region (Rizzo and Wiken 1989). Wetland habitats are likely to shrink over most of Canada, due to warmer, drier climatic conditions. Sea levels may rise by an average rate of 6 cm per decade over the next century (Intergovernmental Panel on Climate Change 1990), and coastal wetlands would be flooded, causing further losses of critical habitats. The temperature of some northern lakes will rise, increasing their suitability for fish of more southerly latitudes at the expense of species that depend upon cooler water.

Recreation and other activities in parks and other protected areas

The well-intentioned desire to experience nature through outdoor recreational activities, such as bird-watching, hiking, photography, fishing, and hunting, can inadvertently result in damage to wildlife habitats. This is often especially noticeable in parks and other protected areas, which, as nature reserves, are favoured locations for these activities.

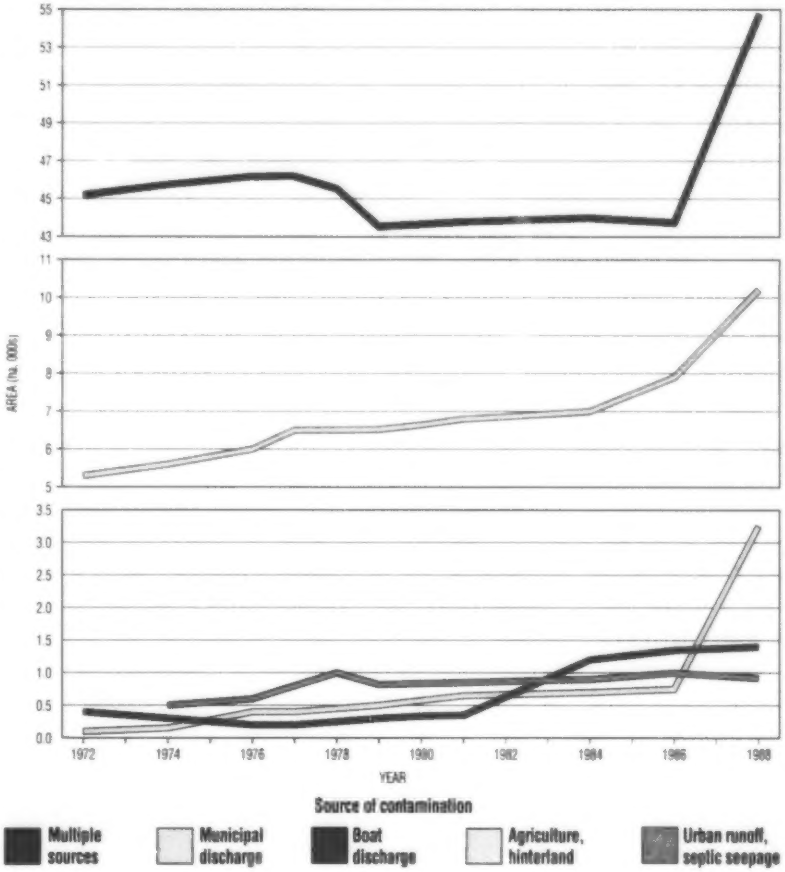
Canada's 35 national parks and park reserves occupy about 18.2 million hectares, or roughly 1.9% of the area of Canada (Nikiforuk 1990). Regrettably, many of these parks are too small to be ecologically self-sustaining, a fact that jeopardizes the very protection that they were intended to afford to natural ecosystems within their boundaries. The same limitation applies to other types of habitat reserves as well. Of the 61 provincial parks in Alberta, for example, 45 are under 1 000 ha in area, and only 2 are larger than 10 000 ha (Bailey 1990). Small areas of protected space offer little assurance of habitat security to large predators such as bears, cougars, or wolves, which require large range areas. In western Canada, for example, only the four national parks in the Rocky Mountains contain enough space to sustain resident populations of cougars (Nikiforuk 1990).

Besides recreation, a variety of other human activities, including logging, mining, grazing, haying, residential and commercial construction, and oil and gas development, are allowed in certain provincial and national parks and other protected areas. Each has its particular impact on the protected ecosystem. Cypress Hills Provincial Park, the second largest in Alberta, contains the Prairie provinces' only nunatak — an area that was spared destruction when the continental ice cap flowed around, and not over, it during the Wisconsin glaciation. As a result, the park preserves habitat conditions that are unique in the region. It supports rare species of plants, is the only nesting and breeding site for certain bird species, and has a very high diversity of wildlife (Bailey 1990). Nonetheless, grazing and logging are permitted in the park, threatening this unusual habitat.

Habitats within parks are also threatened by activities on adjacent lands. New Brunswick's Fundy National Park, for example, is a 20 700-ha "island" surrounded by extensive areas of clear-cut forest (Nikiforuk 1990). Logging outside the park boundaries has degraded the quality and reduced the extent of aquatic habitats within the park as a result of sedimentation and contamination from insecticides and herbicides. Wetland habitats in Wood Buffalo National Park, straddling the Alberta and the Northwest Territories border, have undergone major changes due to upstream dams that have altered water levels and vegetation communities. Point Pelee National Park in Ontario, a Lake Erie sandspit famous as a haven for migrating birds, is surrounded on the landward side of the peninsula by intensively managed croplands. In the case of La Mauricie National Park in Quebec, more than 75% of the borders have been clear-cut for pulpwood (Nikiforuk 1990).

FIGURE 26.6

Marine areas closed to shellfish harvesting due to fecal contamination: British Columbia, 1972–88



Source: Kay (1989).

Ironically, the establishment of protected areas for wildlife can also lead to degradation of habitats by the protected species themselves. For example, in southern Ontario, Long Point National Wildlife Area, Point Pelee National Park, and Rondeau Provincial Park contain remnants of Carolinian deciduous forest, a rare habitat type in Canada. However, the protection afforded in these areas has enabled white-tailed deer populations to increase to such an extent that their heavy browsing threatens the existence of the very habitat that supports them (C.L. Warren, Environment Canada, personal communication).

Of course, outdoor recreation activities are not necessarily limited to parks and protected areas. For example, golf courses are often built on important natural sites. Aside from the radical alteration of habitat due to course construction, soil and water may also be degraded by the fertilizers and herbicides that are used intensively in golf course maintenance. Off-track use of all-terrain vehicles is another increasingly popular pastime, particularly in western Canada. All-terrain vehicles allow greater access to once-remote areas and can cause physical and vegetation damage, especially to sand dunes and other fragile ecosystems.

Loss of security in habitats[1]

The ongoing extension of human activities into wilderness areas requires that serious consideration be given to the overall question of how ecosystem security is being compromised. Basing

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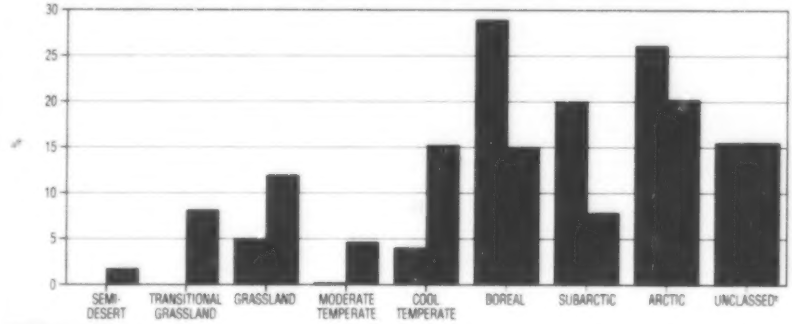
[1] Extracted from review comments provided by Dr. Valerius Geist, Faculty of Environmental Design, University of Calgary.

FIGURE 26.7

Potential impacts of climatic change on habitat types[a]



■ **Current habitat types**
% of Canada currently occupied by various habitat types

■ **Anticipated habitat types**
Predicted composition of Canada's habitat types, in the case of a doubling of atmospheric levels of carbon dioxide (2 x CO_2)[c]

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[a] Based upon the ecoclimatic provinces of Canada (see Chapter 22).

[b] The cordilleran ecoclimatic provinces of western Canada were excluded from the analysis because of the complexities involved in predicting impacts in mountainous terrain.

[c] For predicted distribution of habitat types in the case of carbon dioxide doubling, see Figure 22.10.

Note: Values may not add up to 100% due to rounding errors.

Source: Rizzo and Wiken (1989).

diameter where roads and settlements are absent, roughly two-thirds of Canada remains wild. Since the mid-1970s, however, wild areas in Canada have been reduced by 4% (see Chapter 7). This reduction poses a very serious threat to wildlife, even though only small areas of habitat may be directly lost or degraded. Access roads for mining, logging, and other purposes, seismic trails, and hydro-electric and pipeline corridors commonly allow wildlife no respite from disturbance on what would otherwise be available habitat. These industrial access routes open ever more terrain to hunters, anglers, skiers, hikers, and campers, and to recreationists using 4 x 4 vehicles, all-terrain vehicles, and snowmobiles. Jet boats and amphibious aircraft use waterways to make similar inroads into wilderness areas. The result can be a significant disruption of normal wildlife behaviour. Large mammals will seek to avoid a busy road, by a margin of as much as 400 m on either side of the travelled portion. This amounts to a very large *de facto* loss of habitat.

Whether intentional or inadvertent, harassment of wildlife greatly devalues existing habitat. For example, despite an abundance of seemingly acceptable habitat in Alberta, huge areas where one might expect to find mountain goat, mountain sheep, elk, grizzly bear, and wolf are devoid of these species. They have left the territory under the combination of pressures of year-round hunting and constant disturbance by traffic on access roads. In a similar way, extensive logged areas may appear to be acceptable habitats for some species because of the abundant young growth as a food supply. However, these also may be avoided because of limited cover and high vulnerability due to logging roads. Other forms of harassment can range from photography and intrusive viewing by overenthusiastic tourists to the depredations of dogs and cats. All these factors can result in abandonment or underuse of potentially available habitats.

Conversely, industrial activities may sometimes provide protection to wildlife. There are several locations in British Columbia and Alberta where mountain sheep, elk, deer, bears, and coyotes thrive on active mine sites. In addition, large herbivores frequently invade town sites in national parks, abandoning natural areas in favour of the security from predation afforded in towns. They quickly learn to exploit the altered landscape and its human inhabitants for food and security and can sometimes become a dangerous nuisance in the process.

Continuous human visitation can be just as damaging as continuous chemical contamination to delicate ecosystems. To preserve the value of habitat to wildlife requires thoughtful development and implementation of appropriate security measures. This is an issue that must be addressed more adequately in policies governing access to public lands.

HABITAT CONSERVATION AND RECOVERY

> "...endangered organisms *per se* cannot be preserved. Ecosystems of which organisms are interesting ingredients can, however, be preserved — as long as the ecosphere of which they are parts continues to function in the old natural and healthy way. This realization turns attention more and more to the absolute necessity of preserving wilderness and natural areas, ecological reserves and animal sanctuaries, endangered *spaces* before endangered *species*."
>
> —Rowe (1988)

A landscape approach to habitat conservation

Wildlife conservation has come a long way since laws were first enacted to protect game in Royal preserves. Traditionally, Canada's wildlife habitat has been protected by designating Crown land for conservation or by acquiring private land. This approach — the setting aside of protected areas — is vital: these areas are the anchor for secure and healthy ecosystems. Ultimately, the network should include the coordination and linkage of all protected areas, from wildlife reserves, wild rivers, and landmarks to ecological and heritage sites.

During the 1980s, however, ecologists became increasingly alarmed at the fragmentation of many landscapes in southern Canada. The conservation community recognized that specially designated areas alone could not conserve ecosystems or retain biological diversity. The solution lay in reaching beyond these islands, to develop strategies to protect ecosystems and species diversity across all landscapes (Wildlife Habitat Canada 1991).

This "landscape approach" seeks to minimize habitat disturbance across whole ecosystems, even during the inevitable modifications that industry and urbanization bring. The approach depends on integrated management — all resource sectors working together to mitigate environmental damage and enhance habitats. In many sectors, cooperative management methods are gaining in strength.

Forest landscapes

Gradually, a more holistic approach to forest management is evolving as government, industry, and nongovernment organizations cooperate to reconcile the competing demands made on Canada's forests. The National Forest Sector Strategy, prepared by federal and provincial governments and the private sector, emphasizes conservation forestry and is geared toward long-term maintenance of healthy, stable, and well-balanced forest ecosystems (Canadian Council of Forest Ministers 1987). Whereas previous strategies focused on timber supply, the need to sustain forest ecosystems, including the wildlife habitats that they contain, is gaining recognition throughout the country. Prince Edward Island acknowledges the importance of wildlife habitat in its 1987 Forest Policy and its 1988 *Forest Management Act*. Other provinces have made similar commitments. Many other improvements in overall forest management, such as forestry guidelines, habitat supply analysis, and adaptive management techniques, are helping to lessen the effect of specific forestry operations on wildlife habitats.

Forestry guidelines: Since the 1970s, several provincial/territorial governments have introduced legislative guidelines for forest management that encourage greater integration of forestry and wildlife values. Forestry guidelines for Quebec, Nova Scotia, and Manitoba encourage protection of forest edges and wildlife corridors and place restrictions on the allowable size of clear-cuts, on cutting in riparian zones, and on public access. Guidelines have certain limitations, however. For example, they are not site specific and so may not provide adequate protection to particularly sensitive habitats, such as fish spawning areas, which are especially susceptible to siltation arising from soil erosion. Guidelines may also conflict, as in the case of moose, which require young forests, versus caribou, which depend upon old-growth forest. Furthermore, they are frequently applied only as afterthoughts to logging plans that have already been developed.

Habitat supply analysis: Habitat supply analysis, on the other hand, is implemented prior to the formulation of specific logging plans. Wildlife managers use forest inventory information to identify habitat types and then define the range of species dependent upon each habitat. After setting population goals for each species, managers can determine their minimum habitat requirements. New Brunswick is committed by legislation to using habitat supply analysis to protect wildlife habitats. A computer system predicts habitat supply over an entire cutting area, by integrating information about available timber with habitat objectives. Nova Scotia, Saskatchewan, and Manitoba are also experimenting with this approach. In Nova Scotia, for example, the three-year St. Mary's River Watershed Integrated Management Pilot Project is defining forest/wildlife habitat associations and is developing guidelines for special forest management zones in conjunction with a habitat supply analysis/forecasting model.

Adaptive management: Canada's forest industry is also increasingly using adaptive management: rather than constructing general plans, adaptive management uses on-site information to reduce specific habitat problems. Projects range from developing wildlife habitat handbooks to investigating ground lichen regeneration rates following different cutting treatments and environmental conditions. In British Columbia, for example, industry, government, and nongovernment organizations have launched a five-year program to investigate the relationships between caribou, habitat, and harvesting methods. The Mountain Caribou in Managed Forests Program will ultimately develop a long-term strategy for integrating the management of caribou and timber in the southeastern and central portions of the province.

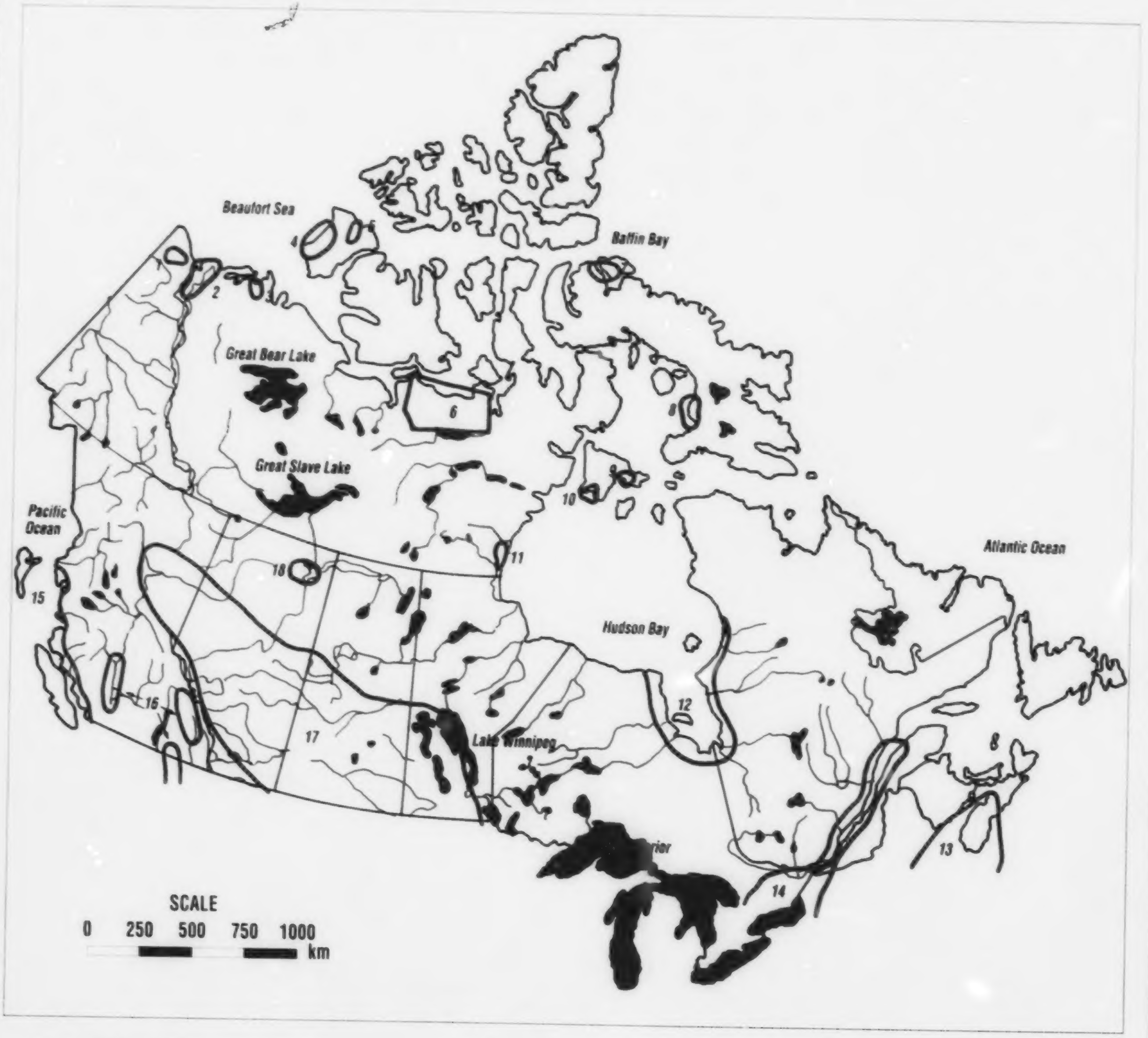
In Manitoba, the Integrated Wildlife Habitat and Forest Management Program aims to develop forest harvest and renewal methods that will protect or enhance wildlife habitats. Over an area of more than 13.5 million hectares, forestry companies are helping to develop inventories of the abundance and distribution of important wildlife habitat types and integrating data into the provincial forest inventory. Other forestry/wildlife programs now ongoing include the Deer Winter Yard Retention Program (Quebec) and the Forest Land Habitat Management Program (New Brunswick).

Agricultural landscapes

Until recently, agricultural policy tended to ignore the effects of agriculture on wildlife habitat. Recently, however, there has been some progress in the rehabilitation of degraded agricultural land and the adoption of more sustainable farming practices (see Chapter 9). Techniques include rotational grazing, winter crop seeding, planting grass along waterways, and delayed haying. Such "conservation farming" benefits both farmers and wildlife by conserving soil and water: the long-term agricultural capability of the land is sustained, and the land provides food and shelter for wildlife at the same time.

FIGURE 26.8

Waterfowl habitat areas of major concern in Canada


Beaufort Sea
Baffin Bay
Great Bear Lake
Great Slave Lake
Pacific Ocean
Atlantic Ocean
Hudson Bay
Lake Winnipeg
rior
2
4
6
8
10
11
12
13
14
15
16
17
18
SCALE
0 250 500 750 1000
km

1. Old Crow Flats
2. Mackenzie River Delta
3. Anderson River Delta (MBS)
4. Banks Island No. 1 (MBS)
5. Banks Island No. 2 (MBS)
6. Queen Maud Gulf (MBS)
7. Bylot Island (MBS)
8. Dewey Soper (MBS)
9. East Bay (MBS)
10. Harry Gibbons (MBS)
11. McConnell River (MBS)
12. James Bay Lowlands
13. Upper Atlantic Coast
14. Lower Great Lakes–St. Lawrence Basin
15. Upper Pacific Coast
16. Intermountain West
17. Prairie Potholes and Parklands
18. Peace–Athabasca Delta

(MBS) Migratory Bird Sanctuary
Note: Map delineations are general in nature.
Source: United States Department of the Interior and Environment Canada (1986).

Since the mid-1980s, new funds, programs, and policies have been a source of optimism for those who wish to restore an emphasis on conservation in agricultural landscapes. Representative programs include the following:

- The Permanent Cover Program of the National Soil Conservation Program (see Chapter 9), initiated by Agriculture Canada, encourages the conversion of marginal agricultural lands on the prairies to forage and wildlife habitat. Since 1987, about 31 000 ha in Alberta and 67 000 ha in Saskatchewan have been placed under long-term vegetative cover (Agriculture Canada 1991). The program aims to remove a further 243 000 ha of cultivated marginal land and other erosion-prone land across the prairies from annual crop production. This amounts to about 1% of the total prairie seeded land (Agriculture Canada 1991). In addition, in 1990, 10 million trees were distributed to farmers for shelterbelt plantings to stop soil erosion and improve wildlife habitat (G.M. Luciuk, Prairie Farm Rehabilitation Administration, personal communication).
- The Prairie Conservation Action Plan aims to protect native prairie and parkland wildlife and habitats. Initiated by nongovernment organizations and endorsed by the governments of Alberta, Saskatchewan, and Manitoba in 1989, the plan supports efforts to assess and quantify the remaining native habitats, to integrate these inventories with local land-use activities and plans, and to protect at least one large, representative area in each of the mixed-grass prairie, tall-grass prairie, fescue prairie, and aspen parkland habitat types. Protection will be achieved through legislation, tax incentives, landowner agreements, purchase, or other means.
- The Prairie for Tomorrow program will complete management plans for 12–15 of Alberta's endangered or threatened species, such as the Piping Plover and shorthead sculpin, by the end of 1991. The three-year program aims to conserve wildlife populations and maintain their habitats through the participation of landowners, grazing associations, and other interested parties.

Landowner stewardship is a necessary and increasingly popular component of conservation efforts. Landowner stewardship, in conjunction with conservation farming and agricultural policy alignment, is a principal component of the North American Waterfowl Management Plan, a $1.5-billion, 15-year program aimed at restoring waterfowl populations to the levels of the 1970s (see also Chapter 6). Signed by Canada and the United States in 1986, the plan has four principal joint venture components in Canada: Prairie Habitat; Eastern Habitat; Arctic Goose; and Pacific Coast. Although by no means limited to agricultural landscapes, one of the plan's major thrusts is in the prairie pothole region of Alberta, Saskatchewan, and Manitoba, which provides critical wetland habitat for more than 50% of North America's waterfowl (Fig. 26.8). Mexico has not yet signed the plan but is cooperating in it, making this a continent-wide effort to conserve and restore wetland habitats. The United States is covering 75% of the cost, Canada's federal and provincial governments will pay 10% each, and the private sector is responsible for the remaining 5%. The plan identifies key habitat areas and establishes habitat objectives. Among other things, it aims to protect and improve about 1.5 million hectares of breeding habitat in the mid-continent region, over 24 000 ha of breeding and migration habitat in the Great Lakes–St. Lawrence lowlands, and more than 4 000 ha on the east coast for American Black Duck migration and wintering habitat (United States Department of the Interior and Environment Canada 1987).

Many other landowner stewardship programs exist:

- In Alberta, the Landowner Habitat Retention Program and Riparian Habitat Conservation Program both encourage landowners to integrate wildlife habitat, including fish habitat, into the management of their lands.
- In Saskatchewan, the Prairie Pothole Project has protected 5 666 ha of privately owned upland waterfowl nesting habitat in the rural municipality of Antler (Saskatchewan Parks, Recreation and Culture 1988).
- The Saskatchewan Upland Protection, Enhancement and Restoration (SUPER) Program also promotes private stewardship, and in Manitoba, the Habitat Enhancement Land-Use Program (HELP) and Critical Wildlife Habitat Management Program promote the conservation and development of habitat on private lands.
- Across the Prairie provinces, Prairie Care offers financial and other support to farmers in critical waterfowl areas to encourage the presence of vegetative cover on marginal croplands. Using funds from the North American Waterfowl Management Plan (within the Prairie Habitat Joint Venture), Prairie Care aims to protect 2–3 ha of upland nesting cover for every hectare of wetland (Poyser 1989).
- In Prince Edward Island, the Montague Watershed Pilot Project provides incentives for land improvement in a 7 300-ha watershed, with about 2 360 ha now under management (Thompson 1990). Under this project, too, about 31 km of hedgerows have been planted on farm fields, another 15.5 km have been rejuvenated, and stream and riparian zone improvements have been undertaken (Thompson 1989).
- In New Brunswick, the Wetland and Coastal Habitat Management Program aims to conserve and enhance coastal wetland habitats through acquisition and landowner stewardship.

Private organizations such as hunting and fishing groups are increasingly encouraging conservation-minded farming. The Ontario Federation of Anglers and Hunters, for example, has developed a component of Ontario's Land Stewardship Program that integrates wildlife habitat objectives with the original soil conservation goal of the program. The program demonstrates how wildlife habitat can reduce soil erosion and also stresses the value of wildlife. Since many native songbirds feed extensively on weed seeds and on insect pests, for example, it benefits farmers to enhance habitat for these birds. In 1988/89, more than 12 000 shrubs and 30 000 trees were planted on Ontario farmland (Reid 1989).

The emergence of wetland conservation strategies and policies reflects the growing concern for Canada's wetland habitats and helps to focus wetland conservation efforts. Virtually every province and territory has implemented a wetland strategy or is in the process of doing so. The Government of Canada will soon adopt the Federal Policy on Wetland Conservation (Government of Canada 1990). The policy will protect wetlands on federal lands and make wetland conservation a fundamental priority of all federal land-use decisions. It will include a system of secured wetlands of national importance. As well, the National Round Table on the Environment and the Economy, Ducks Unlimited Canada, and Wildlife Habitat Canada sponsored a 1990 forum on sustaining wetlands; its recommendations will help in the formulation of a national wetlands conservation strategy (Sustaining Wetlands Forum 1990). These initiatives and others are identifying ways to modify current agricultural policies and to restructure financial incentives to farmers, so that soil and water quality problems are reduced and wildlife habitats are enhanced, without increasing costs to either the farmers or governments.

Urban and industrial landscapes

Wildlife managers have commonly ignored or overlooked urban wildlife, but as Canada's population increases and its cities expand, the state of habitats in and near urban landscapes becomes a critical factor in the effort to maintain the health and diversity of wildlife. A growing number of community-based, nongovernment organizations are initiating urban habitat restoration projects, and several municipalities have begun to integrate wildlife considerations into their plans. The official plan for Ontario's Regional Municipality of Waterloo/South Wellington, for instance, calls for the protection of certain areas because of their value as wildlife habitat.

Recent events suggest that conflicts between industrial development and conservation can be reduced, by both stronger planning and greater public involvement in the protection of wildlife habitats. Environmental damage can be mitigated during any or all phases of a project, including post-project monitoring. In the case of Alberta's Oldman River dam, a comprehensive mitigation program includes developing methods of alleviating the negative effects of the dam on downstream riverine cottonwood habitat (Nilson and Green 1990). In British Columbia, after CP Rail double-tracked its railway line in Glacier National Park, the company reclaimed and revegetated affected areas, planting almost 1 million trees and shrubs, as well as ground covers of wheatgrasses, alfalfa, and fescue (Butler 1990). Abandoned strip mines have been successfully rehabilitated to enhance bighorn sheep habitat in Alberta. Areas were made more secure for the sheep, the landscape was designed, the forage supply was improved, and vital mineral licks were created, resulting in unprecedented production and survival of bighorn sheep. Mitigation has become the main approach of wildlife habitat managers. While it can minimize the impacts of piecemeal development, however, its long-term value is limited due to the incremental nature of much development, and to the inadequate enforcement of conditional approval permits.

Environmental impact assessment prior to development helps to ensure that wildlife habitat values are more effectively considered in proposed industrial developments. One weakness with environmental impact assessment is that it is designed primarily to handle time- and site-specific projects; individual assessments do not adequately deal with the long-term, indirect, secondary, and cumulative consequences of all projects (Richardson 1989). As well, agencies that implement environmental impact assessment and prepare mitigation measures commonly do not have appropriate wildlife habitat expertise. Thus, the conditions they impose on proposed developments are often unsatisfactory for protecting habitats.

There is growing cooperation between the mining sector and wildlife managers to conserve wildlife habitats (see Chapter 11). This cooperation has been effective in British Columbia and Alberta, where the proximity of elk and bighorn sheep paths to coal deposits presented tremendous potential for habitat dislocation. Another success story is the Stadacona Wildlife Management Program in northwestern Quebec, where mine tailings that were contaminating nearby wetlands were removed.

Nongovernment organizations are also playing an increasingly large role in preventing or alleviating damage to habitat caused by industrial developments. In Saint John, New Brunswick, the Nature Trust of New Brunswick and the Nature Conservancy of Canada purchased 1.2 ha of habitat where a hydroelectric project threatened to destroy 40% of the known Canadian population of Furbish's lousewort, one of the rarest plants in the world (MacLeod 1990). The land may still be appropriated for the project, however, and a provincial feasibility study is pending.

Pollutants in Canadian habitats

Environmental contamination is currently one of the highest-profile environmental issues in Canada.

Acidic deposition: Efforts to lessen the impacts of air contaminants on wildlife habitat in Canada have largely focused upon acidic deposition. Since this is an international problem, both the United States and Canada have agreed to significantly reduce acidic emissions (see Chapter 24). It remains to be seen, however, whether the reductions will immediately slow the degradation of eastern Canadian aquatic and wetland habitats. Meanwhile, the task of restoring lost or severely degraded habitats must still be addressed.

Ozone depletion: Global problems necessitate global solutions. To this end, world leaders came together to sign the 1987 Montreal Protocol, a document promising a 50% global reduction in the use of ozone-depleting CFCs and halons. Canada and some European countries went even further in 1990, pledging to eliminate the use of certain CFCs and halons by the year 1997 (see Chapter 2).

Loss of aquatic habitats: Partly in response to habitat loss and degradation due to pollution from urban and industrial sources, the Department of Fisheries and Oceans in 1986 released its Fish Habitat Management Policy, which requires that there be no net loss of the productive capacity of aquatic habitats. This policy remains one of the best national examples of a sustainable development approach to habitat management. The no-net-loss policy does not exclude all habitat loss; rather, it requires that any losses be balanced by habitat restoration elsewhere, which could have a profound impact upon fish management and shoreline development. Today, the Department of Fisheries and Oceans plays an integral role in any development that has the potential to harm aquatic habitats.

Pollution has been a prominent threat to Canada's fresh waters for many decades, especially in the Great Lakes and St. Lawrence River systems (see Chapters 18 and 19). In 1972, the International Joint Commission, a binational organization involving Canada and the United States, established the Great Lakes Water Quality Agreement to restore and maintain Great Lakes water quality. Revamped in 1978 to manage toxic contaminant loadings into the Great Lakes, the agreement takes an ecosystem-based approach to protecting both the water quality and health of the Great Lakes. It was again revised in 1987 to cover atmospheric deposition of contaminants, contaminated sediments, groundwater, and non-point source pollution. The agreement commits not only Ontario, but eight states bordering the Great Lakes, to developing remedial action plans for "Areas of Concern" within their borders (Hartig and Hartig 1990; see also Box 18.3). Remedial action plans must define the environmental problems, their causes, and geographic boundaries, and then identify actions to remedy the problems. Plans have been drawn up for all 43 Areas of Concern, with basin committees, stakeholders' groups, or public advisory groups being established in 32 areas to encourage cooperation among the many institutions involved (Hartig *et al.* 1990).

Many other initiatives aim to safeguard aquatic habitats both federally and provincially. Federal legislation includes the *Canadian Environmental Protection Act* to restrict industrial pollution and the *Arctic Waters Pollution Prevention Act* to respond to the unique threats to the Arctic Ocean. Ontario's Municipal/Industrial Strategy for Abatement (MISA) program aims to reduce effluent releases in the province. In Quebec, two initiatives with potential to curtail point source pollution and restore contaminated habitats in the St. Lawrence River and estuary are the St. Lawrence Action Plan (see Chapter 19) and the proposed National Marine Park at the mouth of the Saguenay River. Although prevention of future pollution is essential, Canada urgently needs more programs like the St. Lawrence Action Plan to clean up aquatic and terrestrial habitats that have been exposed to contaminant dumping for decades.

Parklands

The federal government has pledged to negotiate agreements for the remaining parks required to complete the terrestrial component of Canada's National Parks System by 2000 (Government of Canada 1990). As well, the intensive recreational pressure facing the national parks each year sparked a 1988 amendment to the *National Parks Act*. The change forces park managers to reconcile the goal of ecological integrity of national parks with the growing public demand for increased recreational access to them.

Where critical habitat areas cannot sustain recreational pressures, park managers at both the federal and provincial levels are beginning to restrict public access. An overall approach to the conservation of sensitive sites, parks, and corridors is still lacking, however, and much remains to be done to ensure effective responses to the potential habitat dislocation that may be caused by recreation and other activities in and on the outskirts of parks.

Nonetheless, many recent provincial and territorial efforts are effectively increasing the protection of important areas. For example:

- Quebec has reserved areas totalling more than 3.5 million hectares for future parks.
- Ontario has protected a large portion of the Rouge River Valley, establishing an important precedent in habitat protection within a major urban area.
- Yukon is considering establishment of a parks system to represent all of its natural regions.
- British Columbia's Wildlife Viewing Program is a five-year, $1.7-million initiative that encourages public understanding and appreciation of wildlife, including fish. The program, which began in 1989, aims to develop and maintain 51 viewing sites throughout the province.

Other protected areas

Ecological reserves are areas designated for maintaining natural biological diversity and preserving ecosystems (see also Chapter 7). In its National Registry of Ecological Areas in Canada, the Canadian Council on Ecological Areas has identified all of these reserves as well as other natural areas that conserve ecosystems. Together, more than 2 000 ecological reserves and other natural areas cover more than 6.9 million hectares. About 400 of these areas, comprising more than 3 million hectares, are managed by federal agencies, and the rest by provincial, territorial, and private agencies.

Federally designated Migratory Bird Sanctuaries protect nearly 11.3 million hectares of Crown and private land across Canada. Since 1917, the system has grown from 2 sites to the present 100 (see also Chapter 7). The Government of Canada, by itself or in cooperation with provincial governments, also manages 45 National Wildlife Areas, protecting 305 373 ha of important habitats for migratory birds and other wildlife (see also Chapter 7). Last Mountain Lake National Wildlife Area in Saskatchewan, for example, provides year-round shelter for a wide variety of prairie wildlife as well as for thousands of ducks, geese, shorebirds, and cranes migrating south from their breeding grounds in the Arctic. Other reserves, like Vaseux-Bighorn National Wildlife Area in the Okanagan region of British Columbia, protect unique habitats. Vaseux-Bighorn includes part of the northernmost extension of the Great Basin Desert, which supports California bighorn sheep, Canyon Wren, spadefoot toad, short-horned lizard, and other species found nowhere else in Canada. Each National Wildlife Area is managed to preserve or increase its value to wildlife, while not necessarily excluding reasonable levels of hunting, trapping, fishing, bird-watching, hiking, and canoeing. By 1992, the federal government will also establish a National Wildlife Habitat Network as a component of the proposed National Wildlife Strategy (Government of Canada 1990).

Many Canadian wetland habitats that are already protected by federal or provincial legislation have also been designated under the Convention on Wetlands of International Importance, or Ramsar Convention (International Union for Conservation of Nature and Natural Resources 1986; see also Chapter 7). The Convention supports existing protection by drawing international attention to listed wetlands. Canada has 30 Ramsar sites, totalling about 13 million hectares. The Cap Tourmente National Wildlife Area in Quebec, designated a Ramsar site in 1981, is famous as the principal spring and fall staging area of the Greater Snow Goose. And at Beaverhill Lake in Alberta, the lake and surrounding farmland create an exceptional production and staging area for more than 220 species of birds. At Beaverhill, the local municipal government and interested nongovernment organizations have led the development of a public viewing area and interpretation centre.

Many species of Canadian shorebirds winter in South America. While migrating, they concentrate in great numbers in a few essential locations to feed and rest. A collaboration of government and private organizations has created the Western Hemisphere Shorebird Reserve Network, to promote cooperative international protection and management of critical shorebird habitats. Two areas of the Bay of Fundy — Shepody Bay in New Brunswick and Minas Basin in Nova Scotia — have been designated as hemispheric sites in recognition of their vital importance as migratory stopovers for the highest concentrations of shorebirds in eastern North America.

Nongovernment organizations play a major role in the conservation of our natural habitats. Ducks Unlimited Canada currently has nearly 6 000 active project segments, encompassing a total protected area of more than 6.9 million hectares (Ducks Unlimited Canada 1991). About $32 million of Ducks Unlimited Canada's 1990 budget was allocated to habitat development (improved environments for waterfowl and other wildlife), and the cumulative total of area developed is now nearly 915 000 ha.

Wildlife Habitat Canada is a nongovernment organization that was founded on the philosophy that healthy landscapes are vital if Canada's role as a productive supplier of natural resources is to remain sustainable (Wildlife Habitat Canada 1991). Wildlife Habitat Canada takes a partnership approach to habitat conservation, working along with private landowners, other conservation agencies, governments, and industry to restore, enhance, and protect the whole Canadian landscape. Efforts are focused in four areas: the agricultural landscape, the forest landscape, the northern landscape, and wetlands and other critical landscapes. Wildlife Habitat Canada funds projects and provides financial support for landowner incentive programs, working to ensure a healthy and diverse supply of wildlife on farmlands, in forests, and even in cities.

The Endangered Spaces campaign, spearheaded by World Wildlife Fund Canada, aims at conserving Canada's biological diversity through the protection of a representative sample of each of the country's natural regions (World Wildlife Fund Canada 1990). The campaign brings together 140 groups, making it the largest coalition ever assembled around a Canadian environmental concern.

The Nature Conservancy of Canada is a nonprofit, charitable organization that for over 25 years has secured wildlife habitats on private lands for protection. For example, with funding provided by Wildlife Habitat Canada and with the assistance of the Ottawa Field-Naturalists' Club and others, it has purchased 1 370 ha of the Alfred Bog in southeastern Ontario, the largest continuous peatland in Canada south of the Canadian Shield. This land will be transferred to a local conservation authority for management (Hackman 1989). The Conservancy is pursuing the purchase and protection of about 30 other sites in Canada. It has also been cooperating recently with the Canadian Parks Service and the Canadian Nature Federation to acquire land that will be included in Grasslands National Park in southern Saskatchewan.

Other more local organizations have similar interests. The Nature Trust of British Columbia, for example, since it was established in 1971, has supported about 100 conservation projects involving 164 land acquisitions and grants and protecting over 10 150 ha.

CONCLUSION

Canada's wildlife populations are the envy of the world. The rich wildlife resource — and indeed all of Canada's biological diversity — depends on healthy habitat. Since the mid-1980s, Canadians have made many strides forward in habitat conservation. However, several problems remain: the goals of several resource sectors conflict, resource management programs are complex, and land-use policies are not sufficiently coordinated. Decision-makers still lack an overall policy framework and adequate financial resources to take action. Positive action and regional planning are further hindered by the general dearth of recent data and information on the quantity and quality of habitat for virtually all species of wildlife (see Box 26.2).

In the last five years, particularly promising programs have demonstrated how traditional economic demands on Canada's lands and natural resources can be integrated effectively with the growing demand for environmental stewardship. Since Canada's rich and diverse landscapes are, to a large extent, the source of our greatest wealth, it behooves us to more fully understand their processes so that we may use them with intelligent care.

Over the next half decade, Canada's conservation community needs to embrace a well-articulated wildlife habitat strategy. The strategy not only must embrace all landscapes, it must clearly incorporate more narrow, specific environmental objectives. And it must, above all, recognize wildlife in its broadest sense, retaining a spectrum of habitat to serve all wild plants and animals.

This holistic approach will require imaginative and strategic thinking. It will require a comprehensive ecosystem approach to land use, based on an ecological land classification system. At the same time, Canadians need sufficient data to permit a comprehensive assessment of the state of the country's wildlife habitat, so that

BOX 26.2

Wildlife habitat information: improving inadequate data banks

The world's first attempt at developing a national resource database — the Canada Land Inventory (CLI) — is now more than 25 years old. The CLI, which covers 260 million hectares, is still Canada's most comprehensive resource inventory, but it provides habitat information for ungulates and waterfowl only . To achieve sustainable development goals, Canada requires a more extensive knowledge of the country's resource base.

In 1987, the Stakeholder Group on Environmental Reporting, which was established to assess environmental data collection and reporting in Canada, pointed out several major problems. For example, Canada had no adequate, ongoing national program to monitor the presence of toxics in wildlife and habitats. Canadian data on water quality in freshwater habitats are not comprehensive, tending to be concentrated in specific river basins where major studies have been carried out. In general, insufficient data exist to understand the link between economic activity and environmental quality, such as the quality of wildlife habitats.

Even when adequate data and information are available, they are often difficult to access. For example, the site-specific data collected for environmental impact assessments are widely scattered and, because they are collected in a variety of ways, often difficult to use. Canada has a bewildering array of resource agencies with different information sets and mapping scales. How can timber and wildlife objectives be related when the information is noncomparable by scale, detail, or ecological context?

Canadians need accessible habitat information in compatible formats. Resource sectors must agree on a classification that will allow information to interrelate. Various sectors must also agree on standards: managers need to determine, describe, and measure the minimum conditions that allow a landscape to remain ecologically viable and sustainable on an infinite basis. Even once these systems are under way, extensive monitoring will be needed to chronicle the impacts of land-use changes on habitat quality and quantity.

Fortunately, in recent years, our information base has much improved, largely due to provincial, territorial, and federal programs that identify critical habitats for a variety of wildlife species. These include such programs as British Columbia's Biophysical Inventory, the Northern Land Use Information Series (which covers all of the Yukon and most of the Northwest Territories), Alberta's Key Wildlife Areas and Land Use Referral mapping system, Saskatchewan's Terrestrial Wildlife Habitat Inventory, and New Brunswick's Habitat Supply Analysis Model. Private sector initiatives have also been very important to Canada's store of environmental information:

- The Nature Conservancy of Canada is establishing a network of provincial conservation data centres, operated in cooperation with government agencies. Provincial centres will work with centres in 11 Latin American countries and the United States to form a hemispheric conservation data centre.
- Ducks Unlimited Canada (DU) is using remote satellite imagery to inventory Canada's wetlands. DU now has an inventory of almost all of the wetland basins in the prairie and parkland regions of the Prairie provinces. It is also producing an inventory of habitats in the Great Clay Belt of Ontario (near Timmins) and of prairie upland habitats, through the Prairie Habitat Joint Venture of the North American Waterfowl Management Plan.
- Small groups of dedicated naturalists have compiled bird breeding atlases across the country.

As well, a systematic and ecologically based system of inventories is evolving, called ecological land classification. This system takes an interdisciplinary approach, classifying ecologically significant geographical units based on recurring patterns of soils, landforms, vegetation, water, and climate.

positive action is possible. Programs will require proactive and integrated planning that measures the impact of all human activities on the country's soil, water, vegetation, and other aspects of habitat.

The challenge of the 1990s for the conservation community is to accelerate work with other resource sectors and design viable future landscapes that ensure the integrity of the land. Only then can Canadians improve and conserve our country's environmental quality, maintain our biological diversity, and measure our progress toward sustainable development.

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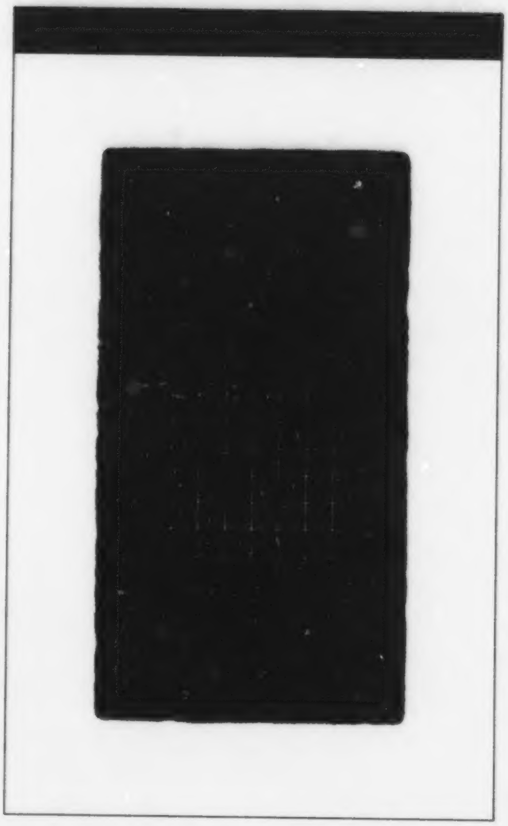

PART V

CONCLUSION

27

COURTESY OF E.W. MANNING, OTTAWA

HIGHLIGHTS

Is Canada's environment in as good a state as we received it from the generation before us? Yes and no. In many ways the environment we pass on to our sons and daughters is healthier, as many of the worst instances of pollution have been improved. But many long-standing environmental problems remain inadequately resolved, and new problem areas and polluting substances continue to be discovered. What we don't know can surprise or even hurt us, and we continue to find major gaps in our knowledge base.

■

Are our actions sustainable? Not yet, although there are signs of progress. Although we are successfully reducing the levels of most pollutants that we measure, many hot spots remain to be cleaned up. Despite improvements in resource management, in many areas more is harvested than can be sustained or replenished.

■

Canadians continue to place greater stresses on the environment than individuals in most of the rest of the world. Progress is evident in the reduction, reuse, and recycling of some materials, but our lifestyle continues to be based on high levels of consumption.

■

There are signs of progress as Canadians begin to respond to the challenge of sustainable development. Canada has been an active international player, addressing global problems such as ozone depletion, acid rain, and climatic change. Canada's Green Plan is now in place. All provinces and territories have established round tables. As well, many industries are adopting environmental policies and codes of practice. Many communities and individuals have taken action at the local level. Nevertheless, despite these initiatives, it is evident that environmental factors are not yet central to the decisions and actions of most Canadians.

■

Major gaps remain in the information needed to report to Canadians on the state of the environment and the impacts of our actions. For many environmental problems there is no consistent national monitoring. As a result, Canadians often do not receive the integrated information needed to support informed decisions regarding the environment.

■

In many respects we are taking better care of our environment than we did 25 years ago. But many problem areas remain, and our attitudes and actions need to change greatly if we are to successfully build a sustainable Canada for future generations. We will have to become not only better stewards of the environment, but better managers of our own actions and their impacts on the Ecosphere. We are at a crossroads — a sustainable path is evident, but we have not yet clearly chosen that path, and we are far from our ultimate destination.

■

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> “Despite the artistic pretensions, sophistication and many accomplishments of humankind, we owe our very existence to a six inch layer of soil and the fact that it rains.”
>
> — Anonymous

INTRODUCTION

The human race is just one of many millions of species on Earth, but it is the only one that has the capacity to determine the fate of the planet. This has not always been so. It is a power that we humans have acquired only recently, as a result of an exponential increase in our numbers and the development of technologies that have magnified our capacity to consume and alter nature's resources. As our ability to transform nature has increased, we have become more inclined to alter the planet to suit our demands than to limit these to what the planet can realistically and sustainably supply. As a result, people have become the dominant agents of environmental change in nearly every part of the globe.

It is estimated that, directly and indirectly, humanity consumes up to 40% of the net primary productivity of all terrestrial ecosystems (Vitousek *et al.* 1986), and the demand is growing. To satisfy this demand, more and more of the global ecosystem is coming under human management, and virtually every segment of the planet is being changed in one way or another. The world's forest cover, for example, has been reduced by an estimated third since 1850 (MacNeill *et al.* 1991) — the result of a direct human assault on the forests to satisfy demands for fuel, timber, and agricultural land. Many other changes, such as soil erosion and acid precipitation, occur as indirect and often unanticipated by-products of our efforts to exploit the riches of the Earth. Human impacts can be detected in the remotest corners of the Earth — in the Arctic, the Antarctic, the mid-Atlantic and mid-Pacific — far from the major centres of human occupation. Even the atmosphere is being rapidly transformed, and with it some of the key chemical and physical processes that nurture life on the planet.

A host of warning signs — from diseased forests to dead lakes to severe ozone depletion over the Antarctic — suggest that not only individual ecosystems but the global environment as a whole may be reaching the limit of its capacity to absorb the stresses that human demands are placing upon it. In recent decades, a growing number of people have begun to question whether we can continue to abuse the environment. Action has even been taken to bring some of our more serious environmental problems under control. But much remains to be done if we are to ensure that the global ecosystem will be able to renew itself in the future as it has in the past.

How can the sustainability of the environment be reconciled with human demands? The world's societies are still working towards a consensus. Nevertheless, it is clear that our pressure on the Ecosphere must be reduced drastically and that this will entail fundamental changes in our attitudes, lifestyles, and ways of doing business.

The environment and the economy

Traditional economic thinking has largely neglected environmental factors. Our economic system functions primarily to provide those items for which there is a market demand. Indeed, an active segment of the economic sector focuses on enhancing that demand. Insofar as the environment is considered at all, it is regarded as a storehouse of potential goods for fulfilling that demand.

The environmental costs of bringing goods to market — the depletion of timber and mineral stocks, the removal of habitats, the effects on human health — are largely ignored. At best, the environmental effects are considered as externalities — things outside the market economy that are difficult to measure and therefore nearly impossible to express in dollar terms. Consequently, these are frequently eliminated from the calculation of costs and benefits. Yet, in Canada and globally, there is tangible evidence that environmental destruction is a real cost: the damage is increasingly visible in the form of polluted air and water, endangered species, and degraded land. The environment is not a “free” good; its costs are a central part of our continuing occupancy of the planet.

Economically, the environment is a form of natural capital, the ultimate source of all goods and services. More importantly, the environment provides the basic life-support systems for ourselves and other species. These life-support systems have an array of requirements that transcend the demands of the marketplace. These include clean air and water, fertile land, climatic stability, and genetic diversity, to name but a few. Their maintenance constitutes a form of life insurance for ourselves as well as all other inhabitants of this planet. Even if the marketplace does not adequately demonstrate the value of these demands, they are just as real as the demand for consumer goods.

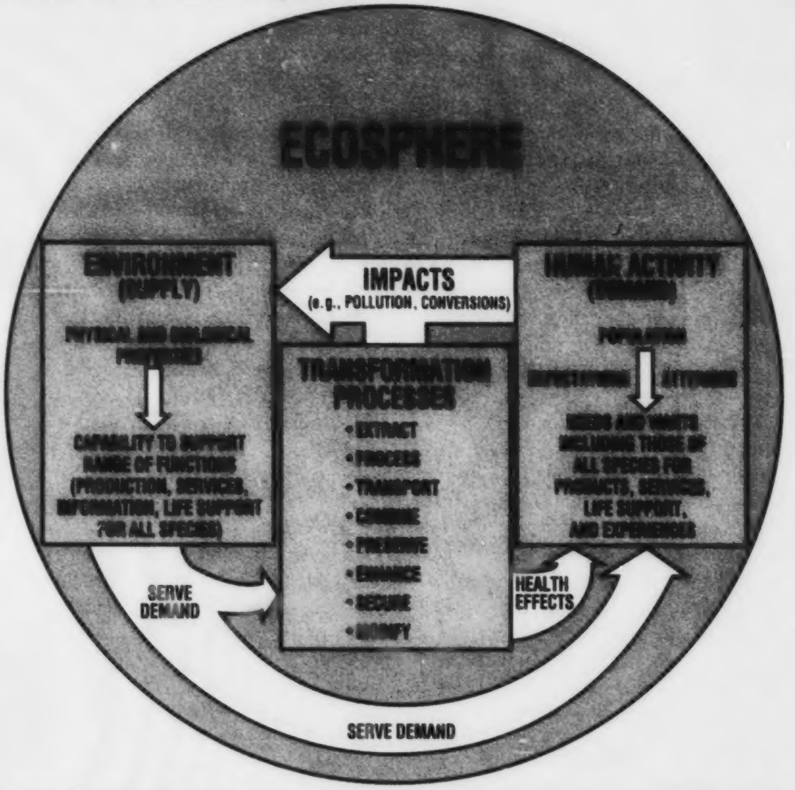
When governments reduce expenditures to control a deficit, they claim to be acting in the name of fiscal responsibility. Put simply, fiscal responsibility means living within one's means. Similarly, ecological responsibility means keeping our demands on the environment within the limits of the Ecosphere's resilience and sustainability. If we fail, we will create an environmental deficit for future generations. But unlike monetary deficits, some environmental deficits can never be repaid.

An Ecosphere approach

Figure 27.1 is a simple supply and demand model that shows how human beings, as part of the Ecosphere and individual ecosystems, act as agents of environmental change. Human needs and wants constitute the demand side of the model, whereas environmental resources make up the supply side. The two are connected by transformation processes, which convert natural raw materials into products and services for human consumption. Environmental change occurs primarily through the transformation processes, which not only deplete the stock of certain natural materials but also return pollutants in the form of wastes and by-products to the Ecosphere. In attempting to satisfy their wants and needs, human beings set up a chain of impacts and feedbacks that affect the characteristics of the environment on which they depend.

FIGURE 27.1

Towards a sustainable system


ECOSPHERE
ENVIRONMENT (SUPPLY)
PHYSICAL AND BIOLOGICAL PROPERTIES
CAPABILITY TO SUPPORT RANGE OF FUNCTIONS (PRODUCTION, SERVICES, INFORMATION, LIFE SUPPORT FOR ALL SPECIES)
IMPACTS
(e.g., POLLUTION, CONVERSIONS)
HUMAN ACTIVITY (DEMAND)
POPULATION
EXPECTATIONS
ATTITUDES
NEEDS AND WANTS INCLUDING THOSE OF ALL SPECIES FOR PRODUCTS, SERVICES, LIFE SUPPORT, AND EXPERIENCES
TRANSFORMATION PROCESSES
• EXTRACT
• PROCESS
• TRANSPORT
• COMBINE
• PRESERVE
• ENHANCE
• SECURE
• MODIFY
SERVE DEMAND
HEALTH EFFECTS
SERVE DEMAND

Source: Manning *et al.* (1990).

By showing how humans transform the environment, the model helps to clarify how we can assess the sustainability of our actions. In particular, it focuses our attention on three central issues: managing the environmental supply, modifying our demands on the environment, and managing the effects of our transformation processes. These are worth examining in greater detail, because each is a critical element in making the overall system sustainable.

The environmental supply

One of the most notable features of almost any ecosystem, when looked at as a source of supply, is the diversity of things it can provide. For human beings, this diversity means that natural environments are potentially multipurpose, capable of providing a wide range of products (e.g., food, wood, water, and furs), services (e.g., flood control, habitat, and cleansing of pollutants), and experiences (e.g., recreation and aesthetic pleasure). The particular mix of purposes that any given environment can fulfil depends on its specific biological and physical characteristics.

For the ecosystem as a whole, this diversity plays an important role: all the elements of the ecosystem are interdependent. Individual species depend on other living and nonliving components of the system for food, shelter, and, in some cases, even reproduction. In a complex and balanced structure of this kind, the removal or alteration of even one small part can have serious repercussions for the entire system.

Increasingly, however, the diversity is being lost as the world's ecosystems are modified to serve specific and often short-term human demands. Foresters and agriculturalists, for example, usually cultivate a narrow range of species at the expense of others that once shared the same habitat. When environments are adapted to serve a single purpose, their ability to serve other purposes is reduced. Other modifications, such as forest clearing and wetland drainage, can also have radical impacts on both the living and nonliving components of the environment.

Any human action has some potential environmental effects. Clearing land for crops alters its ability to support wildlife or recreation. Even apparently benign actions, such as the dedication of land to a specific purpose (e.g., a restricted water supply area), in effect limit the ability of that area to satisfy other demands, such as logging or recreation. If we seek long-term sustainability, our challenge is to understand and manage the effects of the changes we make. Otherwise, these alterations can threaten the ability of an environment to support other functions that are critical not only to its capacity for regeneration, but to the integrity of the Ecosphere itself.

Human demands on the Ecosphere

In the 16th century, when the settlement of Hochelaga numbered barely 1 500 inhabitants, its impact on the environment was minimal. Its waste products, small in quantity and entirely natural in origin, were easily absorbed by the air, the soil, and the waters of the St. Lawrence. Today, it is a far different story. Montreal is the centre of an affluent, industrialized urban conglomeration of close to 3 million people, and the local environment can no longer absorb its wastes, rendering them harmless. Moreover, these wastes — containing thousands of tonnes of vehicle exhaust fumes, industrial chemicals, and synthetic compounds — are of a very different character from those of the past, and much more destructive environmentally.

The growth of Montreal and the change in its impacts on the environment illustrate a much larger global phenomenon. Since 1700, when fewer than 600 million people occupied the planet, the world's human population has grown by a factor of 10, to nearly 6 billion today. Growing human numbers mean less environment per person to meet our basic needs and to absorb the impacts of our activities.

These impacts pose a significant danger. But unlike these past societies, modern industrialization has increased our use of resources and our output of polluting waste several times over. Our human impact on the environment has increased not just 10-fold but many times beyond that. History provides us with many examples, such as those of the ancient Babylonians, the Maya, and the Easter Islanders, of societies whose collapse, at least in part, resulted from the stresses they put on their environments.

Canadians are fortunate in enjoying an environment with a high carrying capacity in relation to the size of the country's population, but even it is showing signs of strain. Because of the country's geography and their high standard of living, Canadians place very heavy demands on their environment. The average Canadian owns or aspires to own a heated single detached home, one or more cars, a television, a refrigerator, a dishwasher, a clothes washer, and a dryer and has easy access to electricity, fossil fuels, and clean water. Frequently, too, we define success according to our ability to acquire such items as an air-conditioned luxury car, powerboats, summer cottages, and vacation travel. To support this level of consumption, Canada uses up more resources and generates more wastes per capita than most other countries of the world. Indeed, the average Canadian's consumption of energy and resources is more than 80 times greater than that of someone living in the poorest countries of the south.

Many of Canada's resources are exported to maintain our high per capita incomes. To a very considerable extent, too, we have supported our affluent lifestyle by depleting our resources, drawing on our environmental capital rather than living off the interest and dividends of a well-managed and renewable environment.

What Canadians and other industrialized peoples now have, increasingly people in the rest of the world want — not only the luxuries but the more essential and useful things such as potable water, electric lights, personal transportation, and refrigeration for perishable food. There is an enormous gulf between the richest and the poorest inhabitants of this planet. While 25% of the world's population now consumes more than three-quarters of its resources, the remaining 75% must get by on the rest, often at less than subsistence levels. The aspirations of these people for a higher standard of living are entirely legitimate, but satisfaction of their demands could create far greater planetary stresses, especially if these gains are achieved through the use of polluting technologies. The problem of sustainability, therefore, is one that must be solved not only at home but in every part of the world.

The impact of our technologies

Technology is the key to the transformation processes described in Figure 27.1, and hence the basis of our ability to alter the environment. A variety of technologies makes it possible to extract resources such as iron ores and convert them into materials such as iron and steel. These can then be fabricated into components such as engine blocks, axles, and car bodies and assembled with other components into complex finished products. These processes are knit together by other technologies that make it possible to transport raw materials to refineries and factories and finished products to markets.

Our bewildering array of processes, materials, and products has direct and often negative impacts upon the environment — depleting resources, altering landscapes, and releasing massive quantities of pollutants and other unwanted by-products. The cumulative effect of these impacts is to reduce the environment's ability to support functions essential to the well-being of humans and other species.

Besides fulfilling demand, technology enhances it. Advanced technologies free us from the demands of subsistence and give us leisure, which in turn creates its own demand for the consumption of natural resources. Having enabled us to satisfy our needs, which are finite, technology now helps us pursue our wants, which are not.

ARE OUR ACTIONS SUSTAINABLE?

What must we do to achieve sustainability? In tackling this question, the authors of the World Conservation Strategy identified three fundamental objectives: maintaining essential ecological processes and life-support systems, preserving biological and genetic diversity, and ensuring the sustainable use of species and ecosystems (International Union for Conservation of Nature and Natural Resources 1980). In the preparation of drafts for a second World Conservation Strategy, attention has also been given to the sustainability of human systems, particularly the implications for health and for social and economic well-being.

Taking these four areas of concern as a framework for evaluating our actions, how far has Canada progressed towards sustainability? This section of the chapter, drawing on the evidence and conclusions of other chapters in this report, attempts to provide an answer. Table 27.1 summarizes the specific conclusions of each of the chapters in relation to these objectives.

Essential ecological processes and life-support systems

The individual character of an ecosystem depends not only on the species it contains but also on the interactions between those species. Some of these interactions are essential to the existence of the system. If they are disrupted, some species may no longer be able to survive or the ecosystem itself may disappear. Some birds, for example, need dead or dying trees for nesting cavities. When these trees are removed from a region, the birds, deprived of an essential element of their habitat, can no longer live there.

Those elements such as air, water, and soil, which provide the basic requirements for life within the Ecosphere, make up our life-support systems. The atmosphere, for example, is a key element of the global life-support system: it provides oxygen and moisture, moderates temperatures, and protects us from ultraviolet radiation. These systems are susceptible to human interference, and disruption of their critical processes could be harmful to life everywhere on Earth.

Conversion and alteration of ecosystems

Canadians have had an enormous impact on their country's natural ecosystems, altering significant features of many of them and completely eliminating others in the course of converting them to other uses. Over time, most of the prairies and southern Ontario have become agro-ecosystems. In the process, much of the natural forest and grassland has disappeared, with some ecosystems, such as the Carolinian forests of southern Ontario and the tall grasslands of the prairies, surviving only as isolated remnants.

Wetlands have also been heavily affected. About 70% of prairie and Ontario wetlands have been converted since settlement, and, in Canada as a whole, 7 874 000 ha of land had been drained for agricultural purposes as of 1989. At the same time, drylands are increasingly being converted to agricultural production through irrigation. In 1988, 893 000 ha of land in Canada were irrigated, more than double the area under irrigation in 1970.

As more forests come under human management, the diversity of tree varieties is being replaced by a narrower range of species. As a result, some animals and birds may be deprived of habitat, and forests may become more susceptible to disease and pest infestations, but as yet the ecosystem effects of this trend are largely unmeasured.

Much of the southern half of Canada has now become a managed ecosystem. Moreover, as our cities expand, other ecosystems shrink. Even environments that had previously experienced little human impact are experiencing significant human impacts, as our demands increase. In the case of activities like the James Bay power project and the Beaufort Sea and Hibernia oil ventures, these impacts can be substantial.

Over the past two decades, however, natural ecosystems have reestablished themselves in some areas. In marginal agricultural areas, particularly in New Brunswick and northern Ontario, for example, unproductive farms have been abandoned. Across Canada, natural regrowth accounted for some 70% of Canada's reforestation between 1977 and 1988. (The remaining area was actively replanted with commercial species; this tends to reduce the diversity of the landscape.) Although changes to natural ecosystems are not necessarily negative and many managed ecosystems can serve a variety of needs over the long term, many of these alterations have occurred without consideration of the long-term and cumulative effects.

To help conserve as much as possible of Canada's ecological diversity, specific areas, such as national and provincial parks, have been set aside in most regions as representative natural ecosystems. Areas with varying degrees of protection encompassed about 7% of Canadian lands in 1991, and new parks and other protected areas are being added each year. Even so, a significant number of ecological regions, particularly marine areas, remain inadequately represented. The creation of these protected areas is an important response to the loss or degradation of ecosystems and habitats, but it is still only a partial solution. As yet, little has been done to manage entire landscapes (including private and public lands) in the interests of sustainability.

Table 27.1

Are our actions sustainable?: summary of key conclusions by chapter

Chapter	Maintain life-support systems	Preserve biological diversity	Sustainable use of species and ecosystems	Human health and quality of life
1. Ecosphere	• environment is the planetary life-support system • the environment and human systems together constitute the Ecosphere	• biological diversity is dependent on the health and survival of the entire system	• human activity continues to threaten the integrity of the Ecosphere and of species	• human welfare is ultimately dependent upon maintenance of the sustainability of the Ecosphere and its component systems
2. Atmosphere	• decrease in common monitored contaminants (lead, SO_2, CO, suspended particulates) • ground-level ozone has not declined	• significant climate warming increases risk of species extinctions • some species very sensitive to acidic deposition	• ground-level ozone may reduce crop yields • pollutants in the air, changed sunlight, may affect photosynthesis, with unknown effects on production	• little is known of health effects of many atmospheric pollutants • over half of Canadians are exposed to unacceptable levels of ground-level ozone
3. Fresh water	• 362 chemical contaminants detected in Great Lakes • phosphorus reduced, many other contaminants continue at unacceptable levels, nitrogen rising in Great Lakes • 30% of urban Canadians continue to dump untreated sewage into water bodies	• contaminants harm species (e.g., Herring Gulls, beluga) • exotic species introduced (e.g., zebra mussel, sea lamprey, Eurasian milfoil)	• contamination limits consumption of fish/shellfish • reduced water use by industry • water shortages viewed as problem of supply, not of demand, many diversions constructed	• 28% increase in those whose water is treated (1975–89) • concern in many areas over contaminants, particularly those found in food chain
4. Oceans	• many areas of concern • wide range of contaminants found in nearshore fauna and in their environment	• few marine ecosystems are protected, designated as parks or reserves	• 1.5 million tonnes per year of fish landed from Canada's oceans by Canadian and foreign fishing fleets —75% of this from the Atlantic • overfishing of certain stocks has produced reduced quotas and fish plant closures on Atlantic coast	• health concerns over contamination of fish and shellfish • loss of jobs in fishery, due to closures, reduced stocks
5. Land	• urbanization of prime lands continues: 60% of urban growth (1966–86) was on prime land • erosion, salinization, compaction affect productive lands, one-fifth of farmland seriously degraded	• alteration of many habitats due to human activity — much of southern Canada has become managed land, affecting its habitat characteristics	• 100 km^2 of land built on annually (1981–86), 60% of which was prime agricultural land • soil degradation is estimated to cost from $600 to $900 million annually in lost agricultural production	• contaminated sites of health concern • concern growing to find acceptable sites for hazardous uses, waste disposal
6. Wildlife	• continuing concern over habitat loss and degradation (wetlands, diverse landscapes, support systems for particular species) • contamination of many habitats • wildlife is a barometer of ecosystem health	• endangered/threatened and vulnerable species numbers grow — 193 now considered at risk • 9 species known to have become extinct and 10 extirpated since original settlement • pressure from exotics (e.g., purple loosestrife)	• hunting/fishing, recreation, forestry, tourism depend on sustained use of species	• many Canadians employed in tourism, hunting depend on wildlife • wildlife worth $9.4 billion annually to Canada based on harvest, use, tourism, etc.
7. Protected areas	• 3 000 areas protect about 7% of Canada, in parks and other types of reserves • all ecosystems are not represented: (e.g., 54% of National Parks System completed)	• concern over extent of protected habitats re: species needs • many protected areas too small to provide all habitat needs of some species	• conflict with demands of forestry/agriculture (i.e., old-growth stands) for access and use of areas • protected areas still subject to pollution and/or overuse	• recreation and tourism benefits come from use/viewing of protected areas • protected areas add to quality of life, preserving natural and cultural heritage
8. Fisheries	• continuing habitat contamination and destruction in coastal and inland fisheries, put fish stocks under pressure • 50% of Nova Scotia nearshore shellfish areas closed due to contamination	• exotic species, including Pacific salmon, rainbow trout, and sea lamprey, introduced to Great Lakes • accidental introduction of zebra mussel	• overcapacity of fishing industry results in overharvesting • Atlantic region depletion of some highly valued groundfish stocks (e.g., cod and haddock) • pelagic fish stocks rebuilding	• limits on consumption of fish, shellfish, on east, west coasts • fishery worth $3.1 billion to Canada • closed plants, loss of fisheries jobs a concern • 1 500 communities depend on fishery
9. Agriculture	• pesticide and fertilizer use is rising • intensification of use of soils — 41% increase in area of cropland since 1930s • many regions report serious soil erosion, salinization, compaction, loss of organic material	• removal of habitat, changes in biodiversity as large areas are managed for food production • all major crops are introduced species • much large-scale monoculture (e.g., prairies) • narrowed genetic base of agricultural animals, plants, and microbes causes concern	• increasing energy and fertilizer/pesticide dependency • many current practices not sustainable in the long term as they degrade resource base • reduction of summerfallow and adoption of conservation practices are helping to conserve soil	• food contaminants well monitored • widespread use of fertilizers and pesticides can affect water quality, adjacent sites
10. Forestry	• 45% of Canada is forested • pesticide use reduced significantly • pulp mill waste down significantly but still a concern • greater herbicide use	• concern over old-growth ecosystems • debate over clear-cutting impacts on habitat: over 90% of harvest is by clear-cut methods • concern over increase in monoculture plantations	• regeneration of 80% of annual cut area, up from 66% in mid-1970s — there are still 200 000 ha more logged than regenerated each year	• 900 000 jobs, 3.4% of GDP from forestry • possible health effects of effluents • potential supply gaps for some mills due to lack of mature supply

Chapter	Maintain life-support systems	Preserve biological diversity	Sustainable use of species and ecosystems	Human health and quality of life
11. Mining	• impact of leachates, acid mine drainage • smelter emissions have been reduced • 315 million tonnes of waste rock and 511 million tonnes of tailings stored • reclamation performance improved	• metals deposited from liquid effluents and atmospheric emissions persist for many years in bottom sediments and can harm fish species	• metal recycling up • reclamation of waste is rising • pit sites not all reclaimed for reuse — many abandoned sites remain from past	• local site impacts on noise, aesthetics • continuing public concern over siting of mines, smelters • nearly 13% of value of Canadian exports in 1990 came from minerals and metals
12. Energy	• SO_x/NO_x from coal use • radioactive waste disposal concerns • thermal effects of power generation • megaprojects impact on ecosystems	• some increased risk to species from thermal effects and pollutants	• Canadians among highest energy users in the world • some positive effects of conservation	• risk from waste, pollutants • human choice of energy use and mix of sources is important
13. Urbanization	• cities concentrate the effects of humans • levels of some measured air pollutants are significantly reduced	• some species thrive in urban setting, but most find conditions altered to the point where their needs are not met	• cities tend to grow where resource base strongest, often consuming their own base, focusing pressures on prime resources • urban centres can be focus for solutions (e.g., recycling, transit, sewage treatment)	• monitored pollution is within acceptable levels in most centres much of the time • beach closures and smog still persist
14. Industries	• estimated 8 million tonnes of hazardous waste produced by Canadians (1988) • 90% of CO_2 is from fuel combustion • significant reductions in pollution levels from pulp and paper/petroleum refining industries	• some species show localized effects from effluents	• fuel efficiency in vehicles and improved emission control have stabilized total emissions despite more vehicle use • pollution levels from most monitored sectors decreased, but only a few sectors are monitored	• potential health risks from some toxic pollutants • pollution is to some extent consumer driven — linked to demands for products, substances
15. Arctic	• arctic systems very fragile, affected areas take a long time to recover • contaminants persist for long time in arctic ecosystems	• bioaccumulation of some toxics at top of food chain • climatic change effects may be magnified, altering habitats significantly	• no restrictions yet on consumption of country food, but contaminants found in species consumed (e.g., whales, seals, caribou)	• increased impact of megaprojects in North, affecting communities and lifestyles • climatic change could melt permafrost with major effects on transport, communities, food sources
16. Lower Fraser River basin	• diverse, productive, and densely populated ecosystem • region shows concentrated impact from human system; waste, pollutants, radically altered/built environment	• five bird species and one mammal extirpated • habitat to two endangered species	• fish face combined threat of habitat deterioration and increased fishing • significant loss of agricultural land • part of estuary and adjacent Boundary Bay closed to clam and oyster harvesting	• solid and hazardous waste management is a major issue; 11% increase in volume of solid waste since 1982 • increased traffic volumes and commuting distances have environmental/economic costs
17. Prairie grasslands	• region is now an agro-ecosystem — 87% of prairie grasslands region now farmland • 22% of wetlands lost since 1955 • reservoirs for power generation, flood protection, irrigation, and water management developed on nearly every major river system	• four extirpated and five endangered species • loss of biodiversity due to monoculture	• original organic matter levels in soils reduced by 40–50%, 6% of improved land suffers from secondary salinization, 5 million hectares affected by water erosion in Sask. and Alta. • intensification on fragile system brings increased environmental risk; irrigated area doubled 1970–88	• water quality close to minimum standards in many areas • potential significant impact of climatic change on habitat and agriculture
18. Great Lakes basin	• reduced phosphorus contamination (e.g., Lake Erie down nearly 50%), but nitrogen levels rising • 362 chemical contaminants detected — number has remained stable since early 1980s • wetland removal continues	• reproductive and deformation problems in Herring Gulls linked to toxics • exotic species introduced (e.g., sea lamprey, zebra mussel)	• cleanup focused on 43 hot spots • cleanup will cost billions and take decades	• residents of Great Lakes have levels of contaminants in their bodies similar to rest of North America • limits on consumption of certain fish species and sizes in several areas
19. St. Lawrence River	• concern for pollution from agriculture, pulp and paper, mines, petrochemical, municipal and industrial effluent • coastal wetlands diminished	• biologically rich area • beluga, some fish species threatened	• high concentration of PCBs observed in American eel and lake sturgeon	• decline in commercial fishery
20. Upper Bay of Fundy dikelands	• 90% of original Bay of Fundy salt marshes converted since settlement • generally stable ecosystem — little change	• no clear records over time, but alterations over time have likely reduced populations of some species	• overhunting and marsh drainage have reduced bird populations significantly since settlement	
21. Toxic chemicals	• widespread low-level contamination evident in all ecozones, even the most remote ones • 70 000 chemical products in use worldwide • PCB and DDT levels down in Great Lakes	• contaminants found in seabirds, polar bears, cormorants, eagles, whales	• some hunting, fishing curtailed due to toxic contamination	• chemicals are a part of modern life • chemicals can pose threats at every stage of their life cycle — use, storage, transport, etc. • uncertainty of health effects, risk

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TABLE 27.1 (continued)

Chapter	Maintain life-support systems	Preserve biological diversity	Sustainable use of species and ecosystems	Human health and quality of life
22. Climatic change	•Canada among world's highest in per capita greenhouse gas emissions •increased gas levels can lead to a rise in temperatures, particularly in North, with risk of significant ecological change	•some species may lose the habitats they require (e.g., coastal wetlands), others have to shift to new areas, possibly facing new competitors	•major implications for forests, agriculture, fishery, many types of recreation, as conditions change •probable sea-level rise	•changes may occur in energy demand, quality of life •drowned shorelines, with loss of property
23. Stratospheric ozone	•global annual average depletion of 0.02% •measured antarctic and arctic ozone holes •risk to photosynthesis process, ecosystems	•risk unknown; could affect photosynthesis; selective survival of species could alter food chain	•impacts not known on agricultural and forest productivity	•increase in UV-B is predicted to lead to increases in skin cancer and cataracts
24. Acidic deposition	•significant deposition affecting much of eastern Canada •50% reduction from 1980 SO_2 levels by 1994 •46% of Canada is highly sensitive to acidic pollutants	•abundance and health of many species affected (fish, loons, trees)	•14 000 lakes no longer have fish in them •most heavily impacted areas coincide with the more productive forests, agricultural lands, and fish habitats in Canada	•80% of Canadians live in affected areas •indications of link to respiratory ailments •damage to heritage buildings, detrimental effects on tourism/sports fishery
25. Solid waste	•10 000 active and inactive dump sites •Canadians among world's most prolific per capita generators of waste — 1.8 kg per capita per day		•4 million tonnes of unrecovered paper waste each year equivalent to over 100 million trees •inadequate reduction, reuse, recycling mean we are discarding our natural resources	•growing demand for waste reduction •problem of where to put volume of waste
26. Habitat change	•habitat is fundamental life-support system •loss and degradation of critical ecosystems continue (e.g., wetlands, grasslands, old-growth forest, fish spawning areas)	•193 species endangered, threatened, or vulnerable due mainly to habitat loss or degradation •some exotic species can threaten native ones (e.g., purple loosestrife, zebra mussels)	•some forestry, agricultural, recreational, and industrial development practices do not sustain adequate habitat for species or maintain other environmental values	•value of nonconsumptive uses of habitat (e.g., bird-watching) often not understood •existence value of species/ecosystems (just knowing it's there) often not appreciated
27. Sustainable development	•Canadians are custodians of a significant part of the Ecosphere •many of our actions continue to harm basic life-support systems	•despite actions to reduce our impacts on species and ecosystems, the list of species and spaces at risk continues to grow	•there are signs of improvement, but Canadians still harvest more than is sustainable or replenished in most resource sectors and damage the productivity of the environment by their actions	•many of the problems are caused by our high demands for the products, services, and experiences supported by the environment •despite some progress, Canadians have not yet clearly chosen a sustainable path

Pollution of the atmosphere

Air pollutants from motor vehicles, industries, thermal generating plants, farms, homes, offices, and many other sources endanger human health and the vitality of ecosystems in every part of the country. Atmospheric currents carry some of these pollutants over enormous distances. Toxic contaminants from the populous south routinely reach even remote regions of the Arctic, where they concentrate in the food chain and pose a potential hazard to the human population.

Canadians have responded to concerns over local air quality and acid rain, and, as a result, average national levels of many pollutants have decreased or at least stabilized over the past 15–20 years. Since 1974, measured levels of total suspended particulates decreased by 45%, while the amount of lead in the air declined by over 90%. By 1994, emissions of sulphur dioxide, the gas primarily responsible for acid precipitation, are projected to be only half of the 1980 level. However, in some areas, such as the Lower Fraser Valley, overall pollutant levels have remained relatively constant, as growth in the numbers of people, cars, and industries has offset the gains provided by cleaner technologies. In other urban areas, such as Saint John, New Brunswick, and many centres in the Windsor–Quebec City corridor, ground-level ozone still occasionally exceeds acceptable health limits. At the same time, we are becoming aware of possible new pollutants that need to be studied and managed — substances such as MMT, for example, an octane booster now being used as a substitute for lead in gasoline.

Changes in atmospheric chemistry caused by human activities are also a major concern because they threaten important life-support functions. These changes have led to depletion of the stratospheric ozone layer and have increased the possibility of significant global warming. Depletion of the ozone layer, now occurring globally at a rate of 0.2–0.3% per year, could expose terrestrial and aquatic life to dangerously high levels of ultraviolet radiation. Global warming could result in climatic changes whose extent and rapidity would cause significant ecosystem change as well as a variety of other problems, such as rising sea levels and an increase in the frequency and intensity of tropical storms. The conditions that now support specific plant and animal species and productive systems, such as agriculture and forestry, could be radically altered. As a result, the viability of many human communities and natural ecosystems would be threatened, and, for fragile ecosystems with long recovery periods, such as those of the Arctic, the effects would likely be magnified.

Canadians have begun to address these issues. With the signing of the Montreal Protocol in 1987, the world took an important step towards checking the emissions of ozone-destroying substances, but because the major ozone-depleting chemicals such as CFCs are extremely long-lived, the depletion of the ozone layer will continue well into the next century. Because CFCs are important greenhouse gases, their elimination will also help to slow the pace of global warming. However, very little progress has yet been made towards reducing emissions of carbon dioxide and other important greenhouse gases. By failing to address these problems now, we only increase the future risks to humans and other species.

Pollution of water

Unlike many other parts of the world, Canada enjoys an abundant supply of fresh water. But as our population has grown, so has the demand on our water resources; some highly populated regions are close to the limits of their immediate water supplies. In addition, many aquatic ecosystems receive unacceptable levels of pollutants from industrial effluents, treated and untreated municipal discharges, and atmospheric deposition. Pollutants may include toxic contaminants, nutrients, oxygen-depleting material, fecal material and other suspended solids, and pathogenic bacteria. Some of these substances may cause immediate harm to humans and wildlife. Small quantities of more persistent toxic materials may accumulate over time in the food chain and eventually cause mutations, genetic damage, reproductive failure, cancer, and other effects in fish, birds, human beings, and other species at the top of the chain. The thinning of the shells of Herring Gull eggs and the incidence of deformed bills, club feet, and organ deformities in cormorants have provided dramatic evidence of the chronic effects of these materials.

Water pollution problems are greatest in the immediate vicinity of large urban and industrial centres. Consequently, major remedial action plans have focused on such areas as the Lower Fraser River, Halifax Harbour, the 43 Areas of Concern on the Great Lakes, and the 50 priority industrial sources targeted under the St. Lawrence Action Plan.

Water quality is measured regularly in many areas, but the lack of a comprehensive nationwide monitoring system makes it difficult to evaluate trends. Nevertheless, in many places the release of some key pollutants has declined, resulting in a levelling off and, in some cases, a decrease in measured levels in wildlife. Concentrations of PCBs in lake trout taken from Lake Ontario, for example, have fallen since 1977. Phosphorus loadings in Lake Erie have also dropped off substantially, making possible the partial regeneration of an ecosystem that some had once pronounced dead. In coastal areas, the number of urban residents served by sewage treatment facilities increased from 57% in 1986 to 62% in 1989, although further progress is still urgently needed. Many industries have improved their pollution controls as well. The pulp and paper industry, for example, has reduced its output of oxygen-depleting material, suspended solids, and dioxins, even though pulp and paper production has increased. At the same time, however, recent shellfish closures on the Atlantic and Pacific coasts are a reminder that additional improvements are needed.

Pollution of the land

The disposal of solid wastes, both domestic and industrial, has become an enormous problem for urban industrialized societies. Canadians produced an estimated 42 000 t of solid waste per day in 1990 and dumped most of it in landfill sites. More than 10 000 active and inactive dump sites are spread across the country; a variety of other sites contain industrial refuse and mine tailings. Some of these — perhaps as many as 1 000 — hold toxic wastes or other contaminants that can leak into the surrounding soils and water table. We have some information about specific sites, but we do not yet know the full scope of this problem. Today waste disposal, and especially the disposal of certain toxic wastes, is much more tightly and effectively controlled than in the past, but many polluted sites remain. Some of these are orphan sites, for which no owner can be found or held responsible for cleanup. Programs for dealing with these highly polluted sites have only recently got under way.

The effects of chemical pesticides and fertilizers also remain a concern. Pesticide use on some crops has been reduced by the use of integrated pest management schemes that utilize a variety of agricultural practices and biological controls as an adjunct to spraying or as an outright substitute for it. However, overall chemical use in agriculture continues to rise, and many believe it is essential if Canadian farmers are to remain competitive. Pesticides are also used extensively on forests, but the amounts have been reduced in the past decade by increased use of integrated pest management and improved application techniques.

Biological and genetic diversity

As the authors of the World Conservation Strategy have pointed out, the preservation of genetic diversity is a way of both insuring ourselves against harmful environmental change and investing in the future. It is the key to keeping our options open, to sustaining and enhancing the productivity of farms, forests, and oceans, and to providing much of the raw material for future scientific and industrial innovation. It is also a matter of moral principle (International Union for Conservation of Nature and Natural Resources 1980). Because Canada contains so many rich ecosystems, the responsibility for preserving genetic diversity sits heavily upon our shoulders. So far it is a responsibility that we have not met successfully, for our demands on the environment continue to threaten not only individual species but entire ecosystems.

Species at risk

In the three years from 1988 to 1991, the number of species at risk grew from 178 to 193. Canada has 46 endangered species (those most at risk), 50 threatened species, and 97 vulnerable species. In part, this increase is due to our expanding knowledge of plant and animal species, but it also reflects the continuing pressure of human activities.

For most species, loss or alteration of habitat or essential growing conditions constitutes the principal threat. In the populous Lower Fraser basin, for example, the Yellow-billed Cuckoo, four other bird species, and one mammal (the Roosevelt elk) have been extirpated, primarily because of human settlement and the resulting changes to their habitat. As well, the practice of monoculture in farming and forestry has reduced the variety of wildlife in many regions. In other ecosystems, native species have been threatened by the introduction of new species, like the sea lamprey and, more recently, the zebra mussel in the Great Lakes.

Toxic contaminants are also a threat in many environments, especially to fish, birds, and mammals that occupy the upper portion of the food chain. Among the species endangered in this way are the Burrowing Owl and the beluga population of the St. Lawrence estuary, where whale carcasses are so heavily contaminated that they are treated as hazardous waste. Herring Gulls in the Great Lakes, though not a listed species, have also experienced deformations and other effects linked to toxic chemicals.

Although the significance of habitat alteration and toxic contaminants is well known, many other factors involved in the extinction of species are not fully understood. We do not know how many environmental stresses individual species can withstand: at what precise point is their survival threatened? Nor do we know the implications for other species or the system as a whole as repercussions are magnified through the food chain. The species in many ecosystems, even those near large centres of population, have not been systematically studied. In Quebec, for example, practically all of the 185 species of fish, the 1 300 vascular plants, and the 115 birds found in the province live at one time or another within 1 km of the shores of the St. Lawrence, an area of considerable human impact. Yet the state of very few of these species has been examined in detail. Until we know more about the needs of various species and their role in ecosystem health, our ability to report on their state will be seriously limited.

Diversity trends

Much of southern Canada now consists of managed ecosystems, with the favoured species being selected for their commercial value. Where bison and mule deer once ranged, beef cattle now predominate, and the land is managed to serve their needs. Cereal grains cover much of the prairies, and row crops and managed pastures dominate the lands of the Great Lakes plain. When forests are replanted, single species usually prevail over a more varied mix.

With the decline in the number of diverse ecosystems and habitats, the potential for loss of species increases, although the overall risk remains largely undocumented. For human beings, the loss of a species is the loss of an opportunity: a vanished species may have carried the key to a new medicine or a disease-resistant stock, or it may have provided the answers that could lead us to a more sustainable system. But the preservation of ecosystems and species is important for other reasons as well; ecosystem diversity is central to the stability of the global ecosystem itself, and the loss of species is irreversible. Beyond that, it can also be argued that species and ecosystems do not exist solely to serve human ends. Human beings, therefore, have no right to eliminate them, even if their existence serves no apparent human purpose.

To protect as much as possible of the world's genetic diversity, gene banks have been established around the world, and efforts have been made to rescue rare plant materials and animal species. But gene banks are not a complete solution: to understand fully the genetic significance of a species, we must study it in its natural habitat. Advances in biotechnology may help us adapt these genetic resources to new needs and changing conditions, but biotechnology can also be a threat to existing species. Canada is cooperating with other nations to develop better controls on the applications of this science, in order to reduce the risk to species and ecosystems.

Sustainable uses of species and ecosystems

A society that uses species and ecosystems sustainably is one that lives off the interest of its environmental capital instead of depleting the capital itself. To do so, society must manage not only the *use* of the environment's resources, but also *demands* placed on those resources. By managing these wisely, the resources can be sustained almost indefinitely.

Productive systems

We Canadians once thought of the environment as a limitless frontier overflowing with inexhaustible resources. We harvested our fish, fur, timber, and other staple resources, giving little thought to their renewal. If stocks ran out in one area, we moved on to another where resources were again plentiful. In the last few decades, however, we have come to realize that even Canada's vast land mass has its limits, and we have gradually adopted new approaches to resource management. Nevertheless, major problems still exist.

In planning our use of water resources, Canadians have traditionally thought in terms of enhancing the supply rather than adjusting their demands to the limits of the sustainable supply, and this attitude continues today. In some parts of the Prairies, for example, current water withdrawals exceed rates of natural replenishment. To meet domestic and agricultural demands and to fuel power generation, Canadians have resorted to extensive and sometimes radical modifications of the environment. To date, 613 large dams and 54 interbasin diversions have been constructed in this country, sometimes causing negative effects such as land salinization, habitat removal, and lowering of water tables.

Farmland is another resource whose sustainability is threatened. Between 1966 and 1986, 1 750 km^2 of Canada's most productive and versatile agricultural land was urbanized. Past expansion has already cost Canada much of its best land, particularly that capable of growing tender fruits and vegetables. In addition, farming adjacent to urban areas is often discouraged because the lands have greater economic potential as future development sites. The building of transportation corridors, the purchase of farms by city dwellers for residential or recreational purposes, and other urban pressures further reduce the productivity of land on the periphery of our cities. Although most of Canada's good farmland remains available for agricultural use, it is a finite resource: we must find better ways of managing the urban encroachment on the countryside.

While the quantity of our best farmland is being reduced, so is the quality of its soils. Most regions report erosion, salinization, and other forms of soil degradation. Erosion is the greatest problem, and it is occurring in some areas at rates more than 25 times greater than the natural rate of soil replacement. Parts of the Prairies have lost over one-half of the original organic material in soils. In areas of Saskatchewan and Alberta, the problem is further compounded by dryland salinity, which now affects 20% of the irrigated land. Altogether, soil degradation is costing Canadian farmers from $600 million to $900 million annually and is considered a long-term threat to continued crop production in many regions.

These losses are largely the result of farming practices such as row cropping, summerfallowing, and the tilling of slopes. Economic pressures have encouraged farmers to maximize short-term productivity and have left the agricultural community few resources for investment in long-term conservation. In addition, quotas and other government programs can lead to practices that are potentially damaging to the long-term sustainability of soil resources. Policies and programs designed to encourage more sustainable farming practices are now emerging. There is growing recognition of both the environmental problems arising from agricultural practices and of the practical solutions to them.

Canadian forest management has improved, but more trees are still harvested than are planted, and the area of old-growth timber continues to decline. In the mid-1970s, only 66% of cut areas were successfully regenerated. By 1988, the proportion had increased to 80%, but 200 000 ha per year still went unrestocked. In the long run, a withdrawal of environmental capital on this scale is not sustainable. Failure to replant in the past has already resulted in supply gaps for mills; in some areas, mills may be closed because of a lack of mature trees. Clear-cutting, particularly in mountainous regions, has exposed some land to erosion, although the practice has largely been curtailed on steep slopes. However, clear cuts in Canada are often several times larger than the maximum permitted in some other countries. Sweden, for example, whose climate and topography are similar to our own, has limited the size of clear cuts in order to maintain landscape diversity and habitat in forested areas.

Many of Canada's commercial and recreational species of wildlife are also stressed. Fish stocks have declined on the Atlantic and Pacific coasts and in the Great Lakes, mainly because of overfishing. Restrictions on commercial fishing have been imposed to allow fish populations to regenerate, but the reduced catches have been a severe blow to some local economies, particularly in the Atlantic region. The shellfish harvest has also been curtailed in many areas, primarily because of habitat contamination, especially from sewage. Oyster beds in the Fraser River delta, for example, have been closed since 1962 due to runoff containing pathogens. Populations of some game species have been threatened by illegal hunting and fishing. In the Atlantic marshes, for example, overhunting has reduced bird populations that had already been diminished by the drainage of the marshes.

Measuring sustainability

To know when an ecosystem is being used sustainably, we must be able to *measure* sustainability. Doing so is particularly difficult, however. Our information about most ecosystems generally comes from those who manage the ecosystems for specific purposes (e.g., farmlands and fisheries). As a result, this information often overlooks other functions supported by these systems. The lack of a balanced and comprehensive view of the system makes it difficult to evaluate the tradeoffs that are being made among potential and actual uses. These could involve choices between using an area for food or forest production instead of wildlife habitat, for example, or using water to absorb waste instead of for recreation or drinking.

A further difficulty is that much information about use of the environment is site-specific and therefore may not reflect the state of the system as a whole. Evaluating the data is also difficult because our understanding of the thresholds of critical functions is incomplete. It is frequently impossible to say, for example, at precisely what point pollution or resource exploitation will have serious impacts on an ecosystem. This limits our ability to understand how specific actions affect the ecosystem's overall health.

Even so, it is clear that many of our actions are harmful to individual species and ecosystems and that their cumulative impact threatens the sustainable use of the environment in the long term. In many of these cases, enough is known to justify remedial action, even as we improve our knowledge.

Changing demands

Canadians make far heavier demands on their environment than most of the world's peoples. Partly because of geography, but also because of attitude and affluence, we are among the highest per capita users of energy in the world. We also generate enormous volumes of waste: this reflects a serious overconsumption of resources and threatens further degradation of the environment. More than a third of municipal waste (36%) is made up of paper and cardboard — 4 million tonnes of it a year, representing the equivalent of 100 million trees. Disposing of these wastes is becoming increasingly difficult. Major cities such as Toronto, Vancouver, and Ottawa have reached the limits of local disposal sites. Vancouver is now shipping waste several hundred kilometres to a site in the interior of the province, and other centres are considering similar solutions. Ironically, Canadians may increasingly find themselves in the position of consuming some of the country's most valuable resources — nonrenewable fuels — to move and bury other resources.

There are signs, however, that Canadian demands are beginning to change. We have moderated energy use, adopting more efficient home heating, better insulation, and more energy-efficient vehicles. Recycling programs and environmentally friendly products have been well received and may help to alleviate the growing waste crisis. As yet, however, Canadians have not significantly changed the consumption patterns that would reduce the overall stress on ecosystems. The private car, for example, is still overwhelmingly preferred to public transport. Many still believe the limits of consumption are far away and so do not feel the need to make a fundamental change in their habits. Our economy is still geared to the encouragement and satisfaction of consumption. These old patterns of consumption, reinforced by existing structures, will take time to change.

The impact on humans

Living in a land that provides most of its citizens with far more than the basic requirements of subsistence, Canadians sometimes forget that they are dependent on the environment. But with the majority of Canada's population living in cities that are the principal sources of many pollutants, and with much of the economy based on natural resources, the quality of the environment is central to our continued well-being.

Health

The environmental issue that touches the majority of Canadians most directly is the effect of pollutants on human health. Airborne contaminants have been linked to a variety of respiratory problems and other disorders. The pollutants include sulphur dioxide and suspended particulates from smelters and other industrial sources, as well as volatile organic compounds (VOCs), nitrogen oxides, and ground-level ozone, mostly from motor vehicles. The presence of persistent toxic chemicals in the food chain has also been documented in many regions — dioxins, PCBs, and organochlorine pesticides in fish in the Great Lakes and other systems, for example, and mercury in fish in rivers contaminated by mill discharges or flooding from new dams. Persistent toxic substances have been associated with a wide variety of chronic health effects, including birth defects, central nervous system disorders, and cancers. In the North, contaminants in the food chain are of increasing concern, particularly given the high level of dependence of many residents, particularly aboriginal peoples, on "country food."

In many other parts of Canada, leachate from waste disposal sites may carry toxic substances into the groundwater. In this way, a significant quantity of toxic contaminants has entered the Great Lakes, particularly Lake Ontario. Many commercial and recreational fisheries in the Great Lakes have been closed or severely reduced because of toxic contaminants, and limits or bans have been placed on consumption of some species.

Knowledge of the health effects of many of these contaminants is still rudimentary and based on a limited number of cases. However, the sum of the evidence clearly indicates danger. As the International Joint Commission recently noted, "when available data on fish, birds, reptiles and small mammals are considered along with… human research, the Commission must conclude that there is a threat to the health of our children emanating from our exposure to persistent toxic substances, even at very low ambient levels" (International Joint Commission 1990).

Community and society

The possibility of both small- and large-scale environmental changes threatens many communities with depletion or destruction of the resource base on which they depend. Global warming would have significant consequences for such vital Canadian industries as agriculture, forestry, fishing, energy, and tourism. Acidification is also a threat, particularly to the forest industry and inland fisheries.

For many Canadians, environmental change could mean economic and social catastrophe. Millions of jobs rely on the extraction and processing of natural resources. For example, the forestry industry alone directly or indirectly employs some 900 000 people, and many other jobs are supported by their spending. The impact would be particularly devastating for single-industry towns that rely on a fish plant, a lumber mill, or some other resource-based activity. Such effects can already be seen in communities on the Atlantic coast, for example, where reductions in fish quotas to try to rebuild stocks have led to the closing of fish-processing plants. Other jobs have been lost to shellfish closures on both coasts, and lumber mills have shut down as local timber supplies have diminished.

Many northern and native communities rely on areas that are increasingly affected by major resource development projects and by pollutants from the south. These communities may lose not only traditional sources of food but also the ability to continue traditional, often environmentally sustainable, ways of life. For many communities, this could mean economic and social breakdown and dependence on imports of food and fuel from the south. This was certainly the experience of some native groups in northern Ontario after the Wabigoon–English river system was closed to fishing because of mercury contamination from a nearby pulp and paper mill. Pollution from this point source was subsequently reduced to virtually zero, but the system is taking many years to recover.

Unpleasant or hazardous facilities present another problem, and communities throughout the country have become increasingly sensitive about having these built in their areas. This sensitivity extends even to necessary facilities, such as those for the disposal of hazardous wastes. Although improved siting, management controls, and technology have made these operations less hazardous, the not-in-my-back-yard or NIMBY syndrome has made it extremely difficult to secure community support for their establishment. Toxic chemical spills and other incidents, such as the PCB fire at Saint-Basile-le-Grand in 1987, continue to fuel public fears while at the same time underscoring the necessity of having adequate disposal facilities for hazardous wastes. The creation of unwanted facilities such as dumps, household toxic waste collection depots, and nuclear waste disposal facilities is an inevitable product of Canada's consumption patterns. Ultimately, these services must go in *someone's* backyard.

SIGNS OF PROGRESS

In 1987, the World Commission on Environment and Development, also known as the Brundtland Commission, issued its landmark report, *Our common future*. Its central recommendations were built around an optimistic objective called "sustainable development," which the report defined as "development which meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development 1987). Achieving such an objective will require major changes not only in the way the environment is viewed but also in expectations and lifestyles. It will affect decisions made at home, at school, and in the offices, boardrooms, and factories of the nation.

The following section will look at a number of initiatives that Canadians have begun — actions by industries, governments, individuals, and groups to develop new approaches to environmental issues and to clean up the problems left by the past. Some of these actions are highlighted in Table 27.2.

> *The Canadian response to the World Commission defined "sustainable economic development" as "development which ensures that the utilization of resources and the environment today does not damage prospects for their use by future generations." It went on to identify the role for each part of Canadian society in making the future more sustainable. The Task Force was composed of government ministers, industry leaders, nongovernment organizations, and academics, who produced a consensus report to guide Canadians in implementing the concept of sustainable development in their activities.*
>
> *— National Task Force on Environment and Economy (1987)*

Responses to environmental problems

Anticipation and prevention

"An ounce of prevention is worth a pound of cure"; a key objective of *Our common future* is to anticipate environmental problems so that we can prevent them or at least avoid making them worse. The Montreal Protocol, for instance, though in part a response to an existing problem of ozone loss, can also be seen as an anticipatory response to forestall the possibility of much more catastrophic levels of ozone depletion. Increased efforts are now under way to develop similar international conventions to deal with other pressing global issues such as climatic change and the maintenance of biodiversity.

In Canada, mechanisms for the anticipation and prevention of environmental problems are increasingly being incorporated into government decision making. Environmental assessment procedures are being strengthened, and environmental goals and criteria are being written into federal–provincial economic and regional development agreements. An Environment Committee of the federal Cabinet has also been established to make federal government policy and decision making more environmentally sensitive.

Multisectoral modelling techniques that can emulate the interactions among the various elements of an ecosystem have improved our limited ability to predict ecosystem impacts. These models have been applied to Great Lakes management, as well as to identifying potential effects of acid precipitation and defining likely impacts of different soil management techniques. The models can identify opportunities for intervention and can help target remedial efforts.

All of these steps are positive, but Canada is still not able to prevent most environmental problems through anticipatory action. It is increasingly clear, however, that an approach of this kind is essential. As we are now finding out, in the case of oil spills, groundwater contamination, and leaking storage tanks, the cost of cleaning up environmental problems is many times the cost of prevention.

Curing past problems: cleanup and regulation

Polluted waterways, leaking wastes from toxic dumps, and contaminated soils and sediments are typical of past damage that now needs to be repaired. To deal with some of the country's worst pollution hot spots, governments, industries, and communities have developed cleanup plans. Remedial programs are now in existence for the Atlantic provinces, the Great Lakes, and the St. Lawrence and Fraser rivers. The St. Lawrence Action Plan, for example, is committed to reducing the amount of liquid toxic effluent from 50 industries to 10% of the 1988 levels by 1993. Specific cleanup programs have begun for Hamilton Harbour, Burrard Inlet, and Halifax Harbour. Major efforts are also under way to clean up the Sydney Tar Ponds and to remove or clean up contaminated soil at old industrial sites such as Vancouver's False Creek area.

Signs of progress: selected examples of environmental initiatives

These are a few samples of actions from across Canada and internationally.

ACTION / LEVEL	ANTICIPATE & PREVENT •Model •Plan •Decision making	CURING PROBLEMS •Clean up •Regulate	TECHNOLOGY •Innovation •Standards	RENEWABLE RESOURCE MANAGEMENT	NON-RENEWABLES •Cradle to grave	CONSUMPTION AND WASTE •Reduce •Reuse •Recycle	BUILT ENVIRONMENT	STRATEGIES •Conservation •Integration	EDUCATION •Knowledge •Attitude
International	•Climatic change convention •Inuit circumpolar strategy	•Montreal Protocol •CITES •Acid Rain Accord	•Work under way on climatic change and biodiversity conventions	•Fisheries agreements •Canada–U.S. Water Quality Agreement	•Control of hazardous waste exports	•Ocean dumping laws	•World Heritage Convention •UN Sustainable Cities Program	•World Conservation Strategy •Ramsar Convention •UNCED, Brazil '92 •World Heritage Convention	•Brundtland Commission •International Institute for Sustainable Development
Partnerships	•National, provincial, territorial round tables •Canada/N.S. Sustainable Development Sub-Agreement	•Remedial action plans (Great Lakes, St. Lawrence) •Orphan sites programs	•Globe 90, 92 Conference/Trade Fair (Vancouver)	•NAWMP •Atlantic Fish Adjustment Plan	•Responsible Care policy of Canadian Chemical Producers' Association	•Canadian Waste Exchange	•Toronto Harbourfront	•National Round Table •National Parks System	•Globe 90, 92 •Brazil '92 •Environmental Partners Fund •Environmental Choice
Federal	•Sustainable development in forestry legislation •Fisheries no-net-loss policy •Federal environmental assessment legislation	•*Canadian Environmental Protection Act* •Panel on Energy R&D •Green Plan	•Integrated pest management programs •Seed banks	•Prairie Care set-asides •National Soil Conservation Program	•NO_x/VOC Management Plan	•Packaging protocol •CCME waste reduction goals	•Home insulation program •Off-oil program •Healthy Housing Design Competition	•Green Plan	•State of Environment Reporting •Environment Week
Provincial / territorial	•Provincial zoning of agricultural land (Quebec, B.C., Nfld.) •Integrated resource planning (Alberta)	•Ontario Pesticide Control Plan	•Site reclamation for mining (e.g., Alberta) •Plastic recycling technologies (B.C., Manitoba, Ontario)	•Property tax breaks for private conservation •Sustainable forest strategy (Ontario)	•Environmental review of siting proposals	•Laws to recycle metal sludge •Laws re: recycling plastics, glass, and metal containers	•Prototype projects for environmentally sensitive housing	•Conservation/ sustainable development strategies in provinces/ territories (P.E.I., Yukon)	•New institutes of environmental studies / sustainability (e.g., Victoria)
Regional / municipal	•Environment in many official plans (e.g., Geraldton, Mission, Ottawa, etc.)	•Household toxic waste collection days in many municipalities	•Zoning controls for noise, fumes •Propane vehicle fleets •improved fuel-efficient transit	•Zoning protection for conservation areas	•Municipal waste action plans (3Rs)	•Greater Vancouver liquid waste management plan •Community composting	•Increased treatment of sewage •Environmental sections in plans •Energy-efficient building standards	•Community sustainable development strategies (e.g., Mission, Peterborough)	•Local environment days, seminars
Private sector	•Long-term environmental strategies for industry (e.g., petroleum, chemical, mining) •Environmental Industry Association	•Codes of practice (e.g., forestry, mining, petroleum industries)	•New emission control technologies •electric vehicles •CFC alternatives	•Multiple use of forests •Conservation farming •Ecotourism	•Research into substitutes (e.g., fibre optics, fuels)	•Recycling of paper increases •Waste oil collection	•R-2000 homes •Industry retrofit for conservation	•Environmental audits •Corporate environmental strategies	•Environmental education for workers
Non-government organization/ community/ individual	•Local strategies (e.g., Clayoquot Sound, Lac St. Jean)	•Community river cleanup days (e.g., Belleville)	•Use of energy-efficient light bulbs, appliances	•Endangered species fund •Caribou Management Plan —Beverly-Kaminuriak	•Reuse containers •Use purchasing power to urge durability	•Curbside recycling programs •Home composting	•Urban tree-planting, cleanups	•Nature Trust (B.C.)	•Community environment days/events •"Green" guides

CCME, Canadian Council of Ministers of the Environment; CITES, Convention on International Trade of Endangered Species; NAWMP, North American Waterfowl Management Plan; UNCED, United Nations Conference on Environment and Development.

Exemplary as these programs are, they still leave many problems untouched. For example, numerous mine tailings, pits, and quarries that were abandoned before most jurisdictions had reclamation regulations still remain and require remedial attention.

A number of new regulatory mechanisms have also come into effect in the last few years, and these will have a noticeable effect on the future output of pollutants. In particular, the *Canadian Environmental Protection Act* (CEPA) of 1988 established a strong legislative base for controlling priority toxic substances (Government of Canada 1988). New regulations under CEPA, for example, will require the elimination of dioxins and furans from pulp and paper effluents by 1994. A variety of other initiatives will control emissions of nitrogen oxides, VOCs, pesticides, sulphur dioxide, and other pollutants and phase out the production and use of CFCs and other ozone-depleting chemicals. In addition, the Montreal

Guidelines, produced for the United Nations Environment Programme in 1985, provide an integrated approach to reducing the 80% of the contamination of the seas that comes from the land. Several provinces have also strengthened their regulatory instruments for pollution control.

Technological innovation

Technological innovations and improvements can make an important contribution to easing environmental problems. Lighter, more efficient motor vehicles equipped with pollution control devices and burning unleaded gasoline have helped improve urban air quality, even though the number of cars on the road has nearly doubled since 1970. Similarly, while pulp and paper mills have increased production, new technology has reduced the quantity of suspended solids and oxygen-depleting material in mill effluent.

Growing demand for cleaner production technologies, improved waste treatment, and reduced environmental impact has nurtured an expanding environmental technology and consulting industry that now generates from $7 billion to $10 billion annually and directly or indirectly employs some 150 000 people. In fact, the industry has now matured to the point where it has established its own umbrella group, the Canadian Environmental Industry Association. At the Globe 90 Trade Fair in Vancouver, several hundred firms demonstrated techniques and skills that could be used to clean up or prevent environmental problems. Globe 92, also in Vancouver, will continue this initiative. Canadian firms can take credit for a number of significant developments: improved incinerator technologies, new cleanup technologies, methods of recycling and reusing waste, applications of computer techniques to natural resource management, and innovative applications of remote sensing to environmental issues.

Government support has assisted in the development of remedial technologies. British Columbia, Manitoba, and Ontario have helped plastic companies develop new recycling processes, and Ontario's Energy Search program is now funding the development of techniques to reduce the fuel consumption of gasoline-powered motor vehicles. At the same time, the federal government's Environmental Choice Program is helping to set standards for environmentally friendly products and processes.

Although achieving a sustainable future will require more than a technological fix, technological innovation is an essential part of the solution.

> *"By definition, if a business does not continuously renew its plant equipment and the resource base on which its profit depends, it simply runs down. Sustainable development is simply applying those criteria to include the entire resource base, the planet."*
>
> *—Maurice Strong, Secretary General, World Conference on Environment and Development*

Progress in resource management

Managing renewables

Sustainable development is perhaps most easily understood in the management of renewable resources. The practice of sustained yield management in forestry, for example, is one of the simplest applications of the concept. It involves limiting the amount of timber cut in a forest each year to the amount that can be regenerated by new growth, thus ensuring a sustained yield of fibre.

Sustainable forestry, however, involves more than just sustaining the yield of a single product. Instead, it requires the management of all of an area's ability to provide goods and services. Logging plans must consider not only a sustained yield of timber, but all of the forest's other uses as well (conserving and protecting water resources, for example, and safeguarding habitat and natural beauty). Plans must maintain the full range of ecosystems and species. On an even broader scale, considerations of sustainability would have to include factors such as energy use, waste management, biodiversity, and contribution to the global carbon balance.

The forest sector has taken several positive steps. At the governmental level, the National Forest Sector Strategy, released by the Canadian Council of Forest Ministers in 1987, adopted an integrated resource management approach of the kind just described, as well as a policy of forest renewal (Canadian Council of Forest Ministers 1987). Sustainable development was also designated as a key mission of the new federal Department of Forestry when it was formed in 1990 and forms the basis for the principles underlying the federal–provincial forest resource development agreements (Forestry Canada 1990).

Industry has begun important initiatives as well. The Canadian Pulp and Paper Association has produced an environmental statement committing members to high standards in sustained-yield forestry, the promotion of multiple use, and the encouragement of environmental awareness among employees (Canadian Pulp and Paper Association 1989). Several firms have also adopted environmental policies or codes of practice. All of these efforts have laid the groundwork for more sustainable forest management. It will be some time, however, before these initiatives produce results; even sustained yield has not yet been achieved on a nationwide basis.

Applied to agriculture, sustainable development involves the maintenance not only of productive land and water resources but also of a broader range of ecological functions. To achieve sustainability, farmers will increasingly become on-the-ground managers of watersheds, habitats, and rural landscapes. They will have to alter some old practices and adopt new responsibilities, perhaps altering planting and crop rotation patterns, leaving stubble on fields over the winter, making greater use of integrated pest management, and maintaining hedgerows, wetlands, or water courses. In many areas, monoculture will be replaced by a more varied usage of the land in order to reduce the vulnerability of crops to pests and to enhance biodiversity. *Growing together*, the report of the Federal–Provincial Agriculture Committee on Environmental Sustainability (1990), reflects growing governmental support for the integration of environmental concerns into agriculture. However, much work remains to be done to make existing farming procedures and support mechanisms compatible with sustainable land use.

Canada's fishing industry, hard hit by declining stocks and contaminated fishing grounds, is also moving to adopt sustainable resource management. Although management of the fishery is the key goal, sustainable management of ocean regions is also increasingly concerned with the role of the sea in toxic buffering, climate control, and other global life-support functions. Major initiatives include the development of information systems, such as the Inland and Coastal Oceans Information Network, to support better integrated management of these resources. As well, the Atlantic Fisheries Adjustment Program was established to improve fisheries science, enhance conservation, and assist diversification. It is hoped that new quota allotment procedures will contribute to better management of fish stocks and reduce the risk of future depletion. International agreements have also been developed for the regulation of fish stocks, but enforcement has proved difficult.

In the North, human impacts are intensifying, making renewable resource management increasingly important. The successful Beverly-Kaminuriak Caribou Management Plan, for example, has brought both environmental and economic benefits to communities on the Manitoba–Northwest Territories border. As a result of investments in superior herd and range management, the once-depleted herd is now stable and supports a sustainable harvest of 19 000 animals annually, as well as an associated hunting and outfitting industry. For the 10 000 people who live on or near the caribou range, benefits exceed $57 million annually. This plan may well serve as a model for other resource management plans in the North.

Renewable forms of energy generation — such as solar, wind, tidal, and small- and large-scale hydroelectric power — provide hope for sustainable energy use because they consume no fuels and have no significant impacts on climatic warming and air pollution. They may have other environmental impacts, however. Large-scale hydroelectric generation has provided a considerable portion of Canada's energy needs for many years now, but concerns are increasingly being raised about the destruction or disruption of ecosystems when massive new installations are built. Many other renewable energy sources exist, their potential largely untapped, but it will be some time before these technologies become practical on a broader scale. Consequently, attention is now shifting to lowering the demand for energy rather than increasing the supply. Better insulation of buildings, more efficient furnaces, light bulbs, and appliances, increased housing density, and other measures can greatly reduce our need for energy and thus diminish the environmental consequences of supplying it.

Because sustainable development seeks to maintain the ability of our ecosystems to support the widest possible range of functions over the long term, resource management must be an integrated process; in other words, decisions about managing and using resources must take all sectors of the environment into account. Alberta has adopted an integrated resource planning approach, and other provincial and regional jurisdictions are using some aspects of multisectoral environmental planning, mainly in the regional planning process. However, the practice is far from universal across Canada.

Nonrenewables: cradle-to-grave management

At first glance, the concept of sustainability would seem to have little relevance to nonrenewable resources like fossil fuels, or to nonreplenishables like metals and aggregates. After all, these are, by definition, finite resources whose supply is diminished with consumption. But although the supply of these resources must inevitably shrink, the products, services, and functions that the resources support will not diminish, and it is these that we want to sustain. Fortunately, a number of options exist to allow these to be provided in perpetuity.

For nonreplenishables like metals, recycling, reuse, and recovery are the key steps to prolonging supply. Many Canadian industries are adopting recycling. In addition to benefiting the environment, the industries are themselves enjoying economic benefits — reduced transportation and dumping charges, for example, and, in some cases, revenue from the sales of "secondary raw materials." Waste exchanges, such as the Canadian Waste Exchange, are emerging in most regions to broker the exchange of materials between companies with waste to dispose of and companies seeking cheap raw materials.

For nonrenewable resources like fossil fuels, the principal conservation option is replacement. In many applications, fossil fuels can be saved by using hydroelectric power or other renewable energy sources instead. Similarly, scarce mineral resources can be saved by using more plentiful materials in their place. Because of the adoption of fibre optics in communication systems, for example, large amounts of copper and other metals can now be used in other applications. It can also be argued that nonrenewables should be used primarily in applications for which renewable substitutes do not exist, or in applications that permit their recycling and reuse. Oil, for example, can be used more sustainably as a lubricant than as a fuel because lubricating oil can be recycled.

The extraction and use of nonrenewable resources can also have serious negative impacts on renewable resources and on environmental quality generally. To address these impacts, a number of industry associations are developing "cradle-to-grave" guidelines and codes of practice for managing their products throughout their life cycles. The Responsible Care policy of the Canadian Chemical Producers' Association is typical of these initiatives. Its codes of practice seek to minimize hazards to human health and the environment during the development, introduction, transportation, storage, handling, distribution, and disposal of chemical products (Canadian Chemical Producers' Association 1990). The Mining Association of Canada has also approved an environmental policy to guide its members and is now developing an environmental code of practice (Mining Association of Canada 1990). In addition, the Canadian Petroleum Association has adopted a far-reaching environmental code of practice to be followed by its members (Canadian Petroleum Association 1989). Although these are positive steps towards the integration of environmental concerns into industrial decision making, they are new initiatives, and such codes and policies do not cover all sectors.

Reducing consumption and waste

Canadians have already successfully reduced consumption and waste in some areas and are beginning to make progress in others. Improved insulation has reduced per capita energy consumption for home heating, whereas more energy-efficient cars are consuming less fuel and producing less pollution. Canadians are also seriously attempting to reduce the volume of residential waste, especially packaging materials, which constitute a third of the municipal waste stream. In 1988, each person produced an estimated 1.8 kg of waste a day. The Canadian Council of Ministers of the Environment plans to cut this amount in half by 2000. An important element of this plan is the National Packaging Protocol, which aims to reduce the total weight of packaging used in Canada by 50% by the same year.

The involvement of individuals, businesses, and communities across Canada in recycling and composting programs signifies a very positive change in attitude towards the environment. By the middle of 1991, the Blue Box recycling program in Ontario was serving more than 2 million households and handling about 14% of the waste from these homes. In many cases, however, recycling is costly, and markets are hard to find for all that is gathered. Until the marketplace reflects the true costs and benefits of environmental factors, this anomaly is likely to continue.

Improving the built environment

Most Canadians live in urban environments. The dense concentration of population in our cities is both a problem and an opportunity. On the one hand, cities eliminate natural ecosystems and produce large amounts of pollution. On the other hand, the population density makes the management of some environmental impacts easier. Sewage treatment, solid waste management, and mass transit are not only more necessary in urban areas, but also more feasible. As the most human-dominated of all environments, the city provides a unique set of challenges and opportunities.

In many centres, environmentally oriented urban planning has resulted in the separation of pollution sources from residential areas and provided infrastructure for the recycling and reuse of wastes. Many recent urban plans have retained open space in the central city, preserved natural corridors and wilderness areas, encouraged the planting of trees on public and private lands, and even promoted the greening of rooftops. In some centres, the rehabilitation and reuse of older buildings have been encouraged, with attendant savings in land, energy, and municipal services. Urban infill and redevelopment in, for example, Toronto and Vancouver are producing beneficial results. Not only do these areas serve a variety of uses, but their population densities encourage walking, cycling, and transit use and enhance heating efficiency.

Although the incorporation of environmental factors into the urban planning process will not be easy, an increasing number of signs indicate that this is happening. Some cities, such as Peterborough, Ontario, have created sustainable development advisory committees, whereas others, such as Burnaby, British Columbia, have created staff positions for environmental or ecosystem planners. In addition, the City of Ottawa and several other communities have adopted conservation or sustainable development strategies as long-term planning instruments. Increasingly, environmental factors are being incorporated into the planning process at the outset, or at least at an earlier stage, thus improving opportunities to reduce negative impacts. The number of success stories is small but growing.

Conservation and sustainable development strategies

Canadians are now engaged in a consultative process at several levels to map out their long-term environmental goals and relate these to their social and economic priorities. Generally, this has involved the creation of ongoing round tables on the environment and the economy. The round tables have been set up by the federal government, the provinces and territories, and some regional jurisdictions. Their membership includes representatives from government, business, and nongovernment organizations, as well as academics and private citizens. Round table deliberations have helped to identify specific roles that businesses, governments, and individuals can play in solving environmental problems and have provided continuing guidance to government in the development of appropriate action strategies. They have also helped to stimulate the implementation of sustainable development by others.

The National Round Table on the Environment and the Economy was established in 1988 and has a fivefold mandate. First, it evaluates the environmental implications of government policies and measures, such as fiscal policy, taxation, royalties, subsidies, and regulations. Second, it evaluates decision-making processes in the public and private sectors and reports on how they might be changed to better reflect the principles of sustainable development. Third, it promotes sustainable development practices in waste management. Fourth, it looks at how external trade, foreign policy, international agreements, and aid can be used to encourage and support sustainable development internationally. Finally, it develops means to communicate the principles of sustainable development to the public to encourage the development of more environmentally responsible values and actions.

The work of the various round tables is now leading to the development of conservation strategies. Prince Edward Island introduced the first of these strategies in 1987, and the Yukon followed in 1990. Other provinces and territories and some municipal and regional jurisdictions such as Lac St. Jean, Quebec; Clayoquot Sound, British Columbia; and Peterborough, Ontario have also begun work on similar documents. Where these strategies are in place, they are becoming the foundation for decisions on long-term policies and programs and are helping to generate new cooperative action on problems involving more than one sector of society.

Greening government

Governments, like private companies and individuals, are both part of the problem and part of the solution. Through several thousands of policies and programs, the federal, provincial, territorial, and local governments have a significant impact on individual decisions and development options. Governments establish rules, subsidize certain actions and penalize others, and provide a substantial amount of the information received by other decision makers. Collectively, governments directly manage over 90% of Canada's environment and establish policies for using the rest. They also fund or regulate most megaprojects and other major construction activities in Canada.

Government programs, traditionally designed to achieve a specific objective, often fail to take account of other concerns that might be affected. As a result, tax incentives, subsidies, or programs that aid one sector sometimes unwittingly damage others. For example, quota systems, designed to better manage agricultural productivity, may contribute to soil erosion on the prairies by making it financially advantageous for grain farmers to plough hillsides or fill in water courses. Similarly, commodity subsidies may reduce species diversity by encouraging monoculture.

Governmental decisions about the location of infrastructure may also influence what other sectors of society do. The location of sewage or water services may encourage development on prime or sensitive environments, on wetlands, for example, prime agricultural lands, or sensitive habitats. As awareness of this problem has developed, government programs and activities have increasingly been subject to environmental review. Indeed, environmental review procedures have been incorporated into all new federal–provincial and federal–territorial development agreements since 1988. As well, government planners have begun to incorporate environmental criteria into new initiatives. However, identifying and modifying the disincentives to environmentally sound behaviour in current government programs remain a major challenge.

As well as building environmental concerns into their programs, governments are also developing new instruments to advance environmental objectives. Alberta's rural tax system, for example, now incorporates environmental factors into the assessment process. One result has been the elimination of tax benefits for clearing or altering marginal agricultural areas. Both Ontario and British Columbia, in an effort to control a growing waste problem, now levy tire taxes to cover the costs of recycling or reusing the discarded product. Several governments, including the federal government, have also begun to examine the use of tradeable permits and other economic measures to limit pollution.

Comprehensive environmental action plans, such as the federal government's $3-billion, six-year Green Plan (Government of Canada 1990), are another important vehicle for realizing essential environmental goals. Building on a broad public consultation process, the Green Plan advocates the concept of sustainable development "to secure for current and future generations a safe and healthy environment and a sound and prosperous economy." As well as outlining new federal policies, programs, and standards for cleaning up, protecting, and enhancing the environment, it contains initiatives to reduce waste generation and energy use and addresses the issues of global environmental security, environmentally responsible decision making, and Canada's environmental emergency preparedness. The plan also builds on existing efforts at the federal and provincial levels. It contains clear targets and goals that will be updated annually in response to emerging issues and priorities.

Partners in solutions

New partnerships involving nongovernment organizations, communities, and businesses are emerging to address environmental issues. The multi-million-dollar North American Waterfowl Management Plan, for example, involves governments, hunters, farmers, and conservation groups in helping landowners and managers to build habitat management into their activities. Many more local partnerships are developing environmental industries, sponsoring community environmental projects, or saving resources. Enterprises in the Port Hope and Cobourg area of Ontario, for example, have saved money and energy by coordinating their transportation needs to Toronto. In other communities, local environmental groups have collaborated with waste management firms and governments to establish recycling programs or to orchestrate cleanups. These partnerships are a reflection of changing attitudes about the importance of the environment.

Changing corporate decision making

Responding to a growing public demand for greater environmental responsibility, many industries have given a high priority to improving their environmental record. Business associations have adopted codes of practice and statements of principle to encourage and help their members meet their environmental obligations. Individual firms have modified procedures and equipment to lessen their impact on the environment, sometimes with additional economic benefits for themselves and others. For many firms, recycling has meant lower costs. A creative assessment of its waste products helped one Ontario coffee manufacturer reduce its overall waste volume, cut disposal costs, and earn extra profits from the sale of by-products for cattle feed. The same firm has also provided the bags in which raw coffee arrives to local municipalities for winter shrub protection. Another laudable initiative is the complete cradle-to-grave management system of a large chemical company, which is developing means to recover all of its products from consumers and recycle them. The firm, like many others, has concluded that an economically viable future depends on accepting full responsibility for the impact of its products and activities.

Managers are also turning to environmental audits as tools for improving their environmental performance, and some companies are producing corporate environmental reports. Those produced by Dow and Noranda, for example, not only highlight the firms' positive initiatives and achievements but also identify problem areas and needed remedial actions. Corporate state of the environment reports are still new, however, and not yet widespread.

The service sector has also become more environmentally aware. Most major Canadian banks have environmental codes either in place or under development. One bank has incorporated environmental risk into its loan review procedures, and some investment funds now target environmentally sound investments. By making environmentally friendly products available, some supermarkets are increasing consumer understanding while strengthening their share of the market. Standards for the environmental acceptability of products are also being identified to assist consumers with their choices. The initial success of these products provides some reassurance that what is good for the environment can also be good for business.

Reducing our impact on the environment

The journey towards an environmentally sustainable future begins with many small steps. Equipped with sound information and knowledge, each person has the capability to do something for the environment as an individual, a worker, a manager, a consumer, and a citizen. Environment Canada (1990) has produced a book listing hundreds of things that individuals can do to protect their environment, and many other green guides have been produced commercially or by nongovernment organizations and communities. In addition, programs such as Environmental Choice help consumers choose environmentally friendly products, whereas initiatives like the Environmental Partners Fund provide financial support for community-based actions to clean up and conserve the local environment. State of the environment reporting also plays a key role in keeping our society informed about our progress towards sustainability.

Polls show that a clean environment is a high priority for Canadians. Environmental issues are prominently and widely discussed in all the mass media, and, although this exposure does not in itself cleanse the environment, it sensitizes public opinion and prepares the way for those actions that do.

A recent survey by Statistics Canada reveals the extent to which Canadians have already made environmentally sound behaviour a part of their lives. Nearly one-third of Canadians have installed low-flow showerheads, and another third report that they prefer and purchase recycled paper products. Twenty-three percent of Canadians with a yard or garden report that they compost their organic waste, and 52% avoid the use of pesticides. The success of environmental days, riverbank cleanups, tree planting projects, and home composting shows that a growing number of Canadians are prepared to act as individuals to achieve a better environment. Offsetting these encouraging and impressive results, however, is the sober fact that Canadians are still among the world's highest consumers of energy and raw materials and among its greatest producers of waste. We have made a good start, but more is needed to put Canada clearly and unambiguously on the path to sustainability.

MEASURING OUR PROGRESS: INFORMATION ON THE STATE OF THE ENVIRONMENT

Measuring the state of the environment

How do we measure something as large and diverse as the environment? The simple answer is: with difficulty. The number of components even in a simple ecosystem is so large and their interactions so complex that it is impossible to describe every element in detail. In a country as large as Canada, the problem is further compounded by the immensity of our geography.

In this report, we have attempted to focus on the trends and indicators that reflect the principal stresses on Canada's environment and to determine how Canadians are responding to these stresses. But even this modest objective has been difficult to achieve because of problems of measurement, limitations of data, and weaknesses in our understanding of some essential processes.

In nearly all areas, the authors have encountered difficulties in securing basic information. Because there has been little comprehensive, nationwide monitoring of key environmental stresses, we lack the data on which overall objective judgements about the state of Canada's environment can be based. Many of the available data have been collected by researchers, industries, or governments for their specific needs. As a result, the kind of information collected and the definitions and standards on which it is based may vary considerably from one place to another, as may the geographical coverage. Even the five-year census, which provides some indication of the level of industrial and economic activity, provides little information about environmental effects. All of this makes comparison on a national or interregional basis difficult and usually impossible.

In some cases, the information available was unique, having been based upon one specific area or obtained from a one-time study. In other cases, it has been possible to document the direct output of pollutants, such as dioxins from pulp mills, but not to document the impacts on the ecosystem except through selected indicators such as the presence of these substances in fish and other forms of wildlife. Often, estimates of current or future effects of environmental disturbances are based on a few test readings, or on extrapolation from a limited number of laboratory tests, or on projections from models of complex systems whose workings are only partially understood. Moreover, relationships between trends in human uses and observed environmental changes are not well known, particularly where the effects are cumulative.

Because it was specific to one area, information gathered for the regional case studies, such as those on the Fraser River or Great Lakes regions, seemed to permit better assessment of the current state of the environment and of changes in key indicators of environmental quality. Indeed, the existence of relatively good data sets was a factor in the selection of case study areas. These chapters focus on the interrelationships between some of the trends and therefore contribute to a better overview of ecosystem health for these regions. However, even for these areas, many important measures of environmental health could not be traced because of lack of information.

In addition to the difficulty of collecting information that is consistent and comprehensive across the country, researchers faced a related problem: how far back the data go in time. The detection of trends requires the existence of long-term records against which current variations can be compared. In many cases, our records are far too short to allow us to do this reliably, because the phenomena we wish to measure — or the technology to measure them — have only recently been discovered. In some cases, we may have just recognized the significance of the phenomena themselves. Our ability to detect trends in environmental levels of microcontaminants such as dioxins, for example, depends on being able to measure concentrations of these substances in the parts per billion or parts per trillion range, but it is only since the early 1980s that we have had the technology to do so. In these cases, we can establish the current state of a problem and compare it with certain standards, but we cannot tell directly whether it is improving or getting worse.

Building better information for the future

Limited though much of our information is, it still clearly indicates a need for action in many areas. But while we are taking action, we must continue to put in place the key measures that will allow us to understand the evolving state of the environment, the impact of our activities, and the effects of our remedial responses. Consistent nationwide information will be needed on critical indicators of air, water, and soil quality, on specific contaminants, on degrading processes (e.g., erosion), and on natural resource inventories and usage. To be useful, this information will have to be current and will have to aid the understanding of environmental issues as well as provide feedback on the effects of management initiatives. As this information comes on stream, it will greatly improve our capacity to respond to existing problems, to anticipate and prevent future problems, and, in general, to make environmentally responsible decisions. Table 27.3 presents an overview of the availability of environmental information (based on issues and sectoral concerns), highlighting both the key information we possess as well as important data gaps. Table 27.4 is a summary of the major categories of information required to address the full range of changes in the state of the environment. A comparison of these needs with the state of current data availability shows that significant challenges remain to be addressed.

As is clear from Table 27.3 and from the text of this report, Canadians need better information to more fully understand the state of the Canadian environment and changes in it, to respond to (and hopefully anticipate and prevent) problems, and to support environmentally responsible decision making.

Acquiring better data is only part of the task, however. We must also improve our understanding of how ecosystems function and how human actions affect them. How much habitat, and with what characteristics, is needed to support a particular species or to absorb the impacts of particular human activities? What happens to the sustainability of an ecosystem if a particular species is removed? How sensitive are different systems to change? Do these systems respond gradually to changes or do they respond radically, but only after a critical threshold is crossed? Indeed, what are the key indicators of ecosystem health?

We also need to know more about the response of an ecosystem to changes resulting from global warming, pollution, and the pressures of increasing human use. Similar questions need to be addressed about the functioning of the food chain and the probable impact of different human demands on the productivity of each of the goods, services,

TABLE 27.3

Data availability for state of the environment reporting

Chapter	Data strengths	Information gaps
2. Atmosphere	• common contaminants (TSS, SO_2, NO_2, CO, ground-level ozone, and lead) monitored in many cities since 1960s • lots of meteorological data for populated areas (over 500 weather reporting stations, many with long records) • Canada contributes to global monitoring of greenhouse gases(CO_2, CH_4) • precipitation acidity and major ions monitored at over 20 sites	• toxics (e.g., some VOCs) require increased monitoring • comparative lack of data on many variables for remote regions such as the arctic and alpine regions
3. Fresh water	• national network to measure water quantity information (e.g., streamflow) • national network on extent of municipal water treatment and sewage infrastructure	• no national system to measure water quality • no national database on beach closures • only selected contaminants monitored on a site-specific basis — often through presence in wildlife species
4. Oceans	• commercial fish catches and level of fishing effort • shellfish closures in most regions • contaminants in seabird eggs • municipal wastewater and pulp and paper discharges	• more information on toxic substances and effects on fish and fish habitats; contaminant levels and state of major sports and subsistence fish, shellfish closures in Quebec • trends in contaminant discharge, northern water quality • drift-net operations, ocean dumping
5. Land	• Canada Land Inventory land capability for agriculture, forestry, recreation, and wildlife in settled part of Canada (circa 1965–75) available • risk potential data (wind and water erosion, etc.) for selected regions • geological and soils data for settled Canada (some need updating) • Northern Land Use Information mapping: Arctic (circa 1970–83)	• no national land-use, land-use change, land degradation, urban land-use data collected consistently and nationwide • data on land-use change around major cities available 1966–86, not collected after 1986
6. Wildlife	• data for species of recreational or economic importance (numbers, range, habitat) • for species known to be at risk (endangered, threatened, vulnerable) there is a comprehensive status report, typically covering population size, exact range, and habitat requirements	• trend data on most species not widely available • few or no data on lower plants, invertebrates, or microorganisms
7. Protected areas	• national inventory of major protected areas by province and territory, internationally protected areas • nationwide classification of ecological areas requiring representative national parks and protected areas	• no consistent national monitoring programs or trend data on environmental quality in protected areas, problem of inconsistent definition • incomplete data on areas partially protected by zoning, recreation areas, or hunting regulations
8. Fisheries	• trend data on fish stocks, fish catches, fishing effort, fleet capacity • data on shellfish closures in most regions • models, estimates of fish stock • comprehensive Inland and Coastal Oceans Information Network • marine ecosystem typology	• stock estimates have historically proven inaccurate for management purposes • broad estimates of fish habitat destruction by acidification • toxicity levels in fish available only for selected species and locations
9. Agriculture	• national and local trend data on farms, extent and use of farmland, crops grown, livestock, inputs such as machinery, fertilizers, pesticides, and management practices such as summerfallow, drainage, and irrigation • agricultural land capability data • agricultural land loss data around urban centres nationwide, 1966–86 • soil risk data (wind and water erosion, salinization, etc.) for certain regions	• environmental implications of many agricultural practices known in qualitative sense (fertilizers, pesticides, monoculture, summerfallow), but extent, severity, occurrence, and rate of change not quantified • national land degradation data not available (estimates based on local data are available) • lack of data on use or impact of conservation practices • lack of data on impact of acidification/ozone/warming
10. Forestry	• data nationwide by province and territory on forest area, forest type (species, age, class, etc.), area cut, area regenerated, area lost or damaged by fires, pests, etc., ownership status • forestry sector economic, employment, and trade data	• inconsistency in definition/terminology between provinces (e.g., successful regeneration) prevents comparisons • lack of trend data on dioxins, furans, and other toxics • lack of data and in-depth analysis on implications of cutting old growth, monoculture regeneration, and other issues
11. Mining	• mining statistics on dollars earned, employment, and production • SO_2 emissions data • lots of site-specific provincial data and research on emissions, etc.	• no regular national reporting (no time series) of area of land used, tonnage, area of tailings, pits, quarries, abandoned mine sites, volume of smelting • overall use of land for mining last reported in 1982
12. Energy	• data on energy generation by source on number of sites, number and size of dams and reservoirs • data on total energy consumption by sector	• no energy land-use data by province • no total inventory of megaprojects and impacts • no data on adoption of energy conservation measures
13. Urbanization	• water: national sewage infrastructure data (1970 to present) • air: National Air Pollution Surveillance Network of 50 localities for TSS, SO_2, NO_2, CO, O_3 • transit supply: Canadian Urban Transit Association • population, households, and housing type: census • housing supply: Canada Mortgage and Housing Corporation • industrial structure: census • rural–urban land-use change, 1966–86	• no nationally consistent database on urban land use, green space, tree cover, water quality, waste generation and management, contaminated land, energy use, transport patterns, or land plans and zoning
14. Industries	• national data for a few regulated and monitored emissions and discharges • comprehensive regional data on emissions and discharges (St. Lawrence Action Plan, Municipal/Industrial Strategy for Abatement, Great Lakes) • interprovincial and international shipping of hazardous waste	• national emissions data available for few industrial sectors • differing jurisdictional roles inhibit comprehensive reporting • reliable information on waste generation and disposal
15. Arctic	• northern land-use information mapping for Arctic (circa 1970–83) • Northern Perspective Series (1985) on general resource use patterns • ecosystem analysis and classification	• baseline data on heavy metals, contaminants, and impacts on ecosystem and health are limited in certain ecosystems • overall, data more limited than in south

(Continued on next page)

TABLE 27.3 (CONT'D)

Chapter	Data strengths	Information gaps
16. Lower Fraser River basin	• data available regionally for air pollutants, point source water effluents, sewage infrastructure, population, housing, vehicle counts, agriculture, forestry, wildlife, and protected areas	• inadequate statistical data to measure overall water quality • no land contamination data • rural–urban land-use change information unavailable after 1986
17. Prairie grasslands	• data available on agriculture use and practice, protected areas, loss of original ecosystems, sewage infrastructure, drainage, and irrigation	• no comprehensive trend data on land degradation, wildlife, waste disposal sites, land use, wetlands
18. Great Lakes basin	• focus on contaminants in water, sediments, and biota • monitoring of 11 critical contaminants in water, sediments, fish, and seabirds at 43 Areas of Concern • data on fish stocks and catches	• little monitoring of contaminants at source • few data on economic impacts of contaminants • few human tissue contaminant data — some recent specific studies • no data on beach closures and other recreational impacts
19. St. Lawrence River	• detailed data on the hydrodynamics of the river • detailed information on natural resources of commercial importance (fish, waterfowl)	• no good time series indicators of overall environmental condition • lack of data on recreational activities, tourism, sport fishing
20. Upper Bay of Fundy dikelands	• land-use change information for study area	• limited systematic data on local wildlife populations
21. Toxic chemicals	• monitoring of regulated contaminants in air and sediments, at effluent source in water, and in indicator species	• more trend data required • more research/assessment of the long-term, widespread low-level effects of contaminants on ecosystems
22. Climatic change	• trend data on global temperature changes and greenhouse gases are consistent with global warming theory • complex models allow generalized prediction of possible ecosystem change and implications for forestry, agriculture, fishing, flooding, etc.	• most models do not show progressions but estimate end of state conditions given certain predicted changes • general predictions, which are difficult to translate to specific regions or economic sectors • effects of warming on precipitation patterns are uncertain
23. Stratospheric ozone	• stratospheric ozone measurements in arctic, antarctic, and temperate zones — short record • monitoring of ozone-depleting substances as they become regulated • correlation of increase in UV-B to skin cancer and cataracts is anticipated (data exist to monitor this relationship)	• unclear what the natural ozone fluctuations are • models may not be properly calibrated; ozone depletion seems to be happening faster than models predicted • ecosystem effects not known, but risk to photosynthesis process is expected
24. Acidic deposition	• SO_2 emissions — key SO_2 sources and levels monitored • SO_2 trend line data exist • terrain sensitive to acid rain mapped • target SO_2 levels set for aquatic resources • monitoring sites and validation targets exist in eastern Canada — for calibration	• deficient baseline data on many areas of concern (no. of lakes, soils, species abundance) likely to be affected • difficulty in isolating acid rain effect from other effects (climatic change, infestation, effects of management) • specific acidity tolerance levels not known (e.g., trees, human health, agricultural products, wildlife) • monitoring network is sparse
25. Solid waste	• national survey in 1988; self-reporting by province of waste generation • Ontario survey on waste generation and composition • national data on waste management to be collected for the National Packaging Protocol	• no nationally consistent data on generation/composition • data vary between federal level, provinces, municipalities, and private sector on definition, concepts, and coverage • no trend data • all recycling data are case-specific or short-term
26. Habitat change	• data of varying coverage and quality available on human activities competing with habitat (e.g., forest cutting and regeneration, farmland area and change, wetland change, rural–urban land conversion to 1986) • Committee on the Status of Endangered Wildlife in Canada list of endangered, threatened, and vulnerable species (habitat needs for species at risk)	• no national program for monitoring trends in quantity, quality, use, or regulation of habitats; data are sparse • limited productivity response data or defined thresholds, carrying capacity of habitat for wildlife species (some specific data for some species in Alta., B.C., and Ont.) • no current change data for competing land uses: rural–urban, forestry–agriculture
27. Sustainable development	• a few nationwide data sets exist to allow the identification of ecozones and some measures of carrying capacity (Ecological Land Classification, Canada Land Inventory, soil landscape units)	• very little information to allow integrated ecosystem-based analysis or planning • significant gaps in knowledge of the relationship between the characteristics of the environment and many of the goods, services, and values it supports

and experiences supported by the environment. What are the cumulative effects of human actions? Only when these relationships are clearly understood will we be able to identify our most essential information needs and judge the sustainability of the trends we monitor.

Indicators

Just as a pulse or a temperature can give us valuable information about a patient's health, measures of certain critical factors can also serve as important measures of the environment's health. These factors are known as environmental indicators. Essentially, environmental indicators reflect the state of some key aspect of environmental quality (e.g., PCBs in seabird eggs), natural resources (e.g., the ratio of regenerated forest to harvested forest), and related human activities (e.g., waste produced per capita). Because they show how these factors change over time, these environmental indicators

Information needs for state of the environment reporting

State of the environment reporting involves the monitoring over time of fundamental descriptors or attributes of the environment and the human impact upon them. The principal categories of information covered by state of the environment reporting include the following:

Components of the environment

- biological and physical characteristics of the atmosphere, hydrosphere, lithosphere, and biosphere (e.g., climate, chemistry, physical properties)
- biota (e.g., presence, diversity, numbers)
- resource capability (e.g., land capability, water recharge capability)

Stresses

- levels of contaminants in the environment (e.g., furans, dioxins, nitrates, sulphur dioxide, leachates, CFCs) in air, soil, water, biota, and other environmental media
- sources of contaminants (e.g., outfalls, industrial sources, non-point sources, inventory of processes used to create contaminants)

Ecological responses to stresses

- changes in the environment (e.g., global warming, acid rain, ozone depletion, endangered species, biomagnification in food chain)
- human health effects (e.g., incidence rates, geographical distribution, and other links to environment)

Human activities

- uses of environmental resources (e.g., land use, water use)
- consumption of natural resources (e.g., forest harvest, paper consumption, take of fish or wildlife, mineral extraction)
- management patterns (e.g., intensity, monoculture, soil depletion)
- stresses due to human activity (e.g., waste production, urban growth, ocean spills, contaminant production, orphan mine sites)

Management response

- measures of activity (e.g., area protected, sites rehabilitated, amount recycled, sewage treated, trees planted, areas subject to environmental planning/controls)
- energy use/efficiency (e.g., appliance efficiency, change in renewable/nonrenewable mix, public transport use, energy input for production of key goods and services)
- institutional response (e.g., regulation, taxation and subsidies relating to environmental objectives, environmental review procedures, conservation strategy development, international activities)

make it easier to judge how the environment is responding to stresses and to the remedial actions we take. Ultimately, they help us to determine how successfully we are progressing towards our environmental goals.

In 1990, Canada established a task force to prepare a national set of environmental indicators. After examining several hundred possible indicators, the task force released its preliminary list in 1991 (Indicators Task Force 1991). The list includes measures of causes of environmental change, symptoms of the changes, and consequences of these changes. These indicators provide a starting point for the systematic monitoring of changes in the state of Canada's environment. The challenge now is to build as strong a set of measures for environmental analysis as we have for economic analysis. A further challenge will be to present this information, some of which is highly technical, in ways that will facilitate its use in everyday decision making by individuals, businesses, and governments.

Integrated monitoring

An important new program of integrated monitoring, arising out of the federal government's Green Plan, should help to fill several of these information gaps. This program will involve a number of partners from all levels of government, as well as the private sector, in the comprehensive monitoring of a number of sites. By collecting information that is nationally consistent and addresses the biological, physical, social, economic, and other aspects of the environment, this monitoring should enhance our ability to understand environmental changes on an ecosystem basis. Integrated monitoring may also provide a better baseline against which to measure the effects of human actions and the effectiveness of management responses.

Environmental accounting

Another new initiative, environmental accounting, is intended to raise the profile of environmental considerations and give them at least equal status with economic factors in the decision-making process. Traditional economic indicators, such as gross national product or the employment rate, largely ignore the state of the environmental resource on which the economy is built. For example, employment numbers as a measure of economic well-being do not consider whether the jobs they record are based on creating a stronger resource base or on short-term gains founded on environmental exploitation or degradation. Current national accounting procedures, which primarily reflect rates of consumption, are blind to whether that consumption has been produced by the sustainable use of resources or whether it has been achieved at the expense of present or future environmental capital. Environmental accounting, based on sound information on the state of our resource stocks, is intended to rectify this omission by building environmental costs and benefits into our measures of economic performance. Some values, such as forest depletion or soil degradation, can be translated fairly directly into dollars. Others — such as biodiversity, the buffering of toxic substances, and contributions to global warming — will be harder to quantify. Much work will be required to refine these measures, but it is hoped that they will bring a new level of environmental sensitivity to our decision-making processes.

Towards better environmental decision making

Information is vital to sound environmental decision making. This is particularly true today, when we are attempting to set right the mistakes of the past and chart a more responsible course for the future. Improved environmental reporting will play an important role in informing decision makers. This document is part of that process. So, too, are the increasing number of reports covering sectoral concerns such as forestry (e.g., Forestry Canada 1991) or dealing with issues from a provincial or local perspective. The emergence of corporate environmental reports is another positive development that will help to identify problems and target preventive or remedial actions. With more and better information becoming available about the state of the environment, Canadians will be better able to address environmental issues at all levels.

There are 27 million environmental decision makers in Canada and nearly 6 billion worldwide. A better environment ultimately depends on better decisions by all of them. Although this report has documented many instances of improved environmental behaviour, there are still many areas where the effects of our actions or inactions are threatening the sustainability of the environment. It is also clear that we are only beginning to understand the full range of our impacts on the environment and its impacts on us. Here is a clear instance in which what we don't know *can* hurt us. Better environmental information is essential to a sustainable future.

STEWARDSHIP

With the second largest land mass in the world, Canada is the custodian of a significant portion of the global environment. Our country has a quarter of the planet's wetlands and freshwater resources, extensive arctic and boreal ecosystems, and the longest coastline of any nation in the world. What we do with our resources can have global implications. Our boreal forests, for example, are one of the world's more important carbon sinks, helping to buffer the effect of humanity's increasing output of carbon dioxide. Depletion of these could ultimately affect not only our own climate but that of the entire Earth. We must, therefore, exercise global stewardship, not only as a form of life insurance for ourselves but for all the world's living organisms. The quality of our stewardship is of central importance to the world's ecological base.

In many respects, we are taking better care of our environment than we did 20 or 30 years ago. We have developed new means of environmental management, and we have replaced or regulated some of our most polluting technologies. Many of the more visible problems are being addressed, particularly those involving pollution hot spots or toxic substances. But Canadians are still pursuing a lifestyle based on high levels of consumption and waste. Despite the emergence of new institutions like the round tables, the development of conservation strategies, and the adoption of environmental codes by industry and governments, environmental factors are not yet central to the decisions and actions of most Canadians. Nor have we put in place the mechanisms for dealing with global problems such as climatic change, deforestation, and desertification.

Is Canada's environment in as good a state as we received it from the generation before us? Yes and no. In fact, the environment we pass on to our sons and daughters will in many ways be healthier than the one we inherited. But many long-standing environmental problems remain inadequately resolved, and many new ones have been discovered. Overall, Canada is not yet on a sustainable path.

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acidic deposition (also known as **acid rain** or **acid precipitation**): Refers to deposition of a variety of acidic pollutants (acids or acid-forming substances) on biota or land or in waters of the Earth's surface. Deposition can be in either wet forms (i.e., rain, fog, snow) or dry forms (i.e., gas, dust particles) (modified from Chapter 24).

acute toxicity: State of being toxic enough to cause severe biological harm or death within a short time, usually 96 hours or less (modified from Upper Great Lakes Connecting Channels Study, Management Committee 1988). See also *chronic toxicity*.

ammonia nitrogen: Nitrogen in the form of ammonia (NH_3). See also *nitrogen fixation*.

anadromous: Refers to species, such as salmon, that migrate from salt water to fresh water to breed (Upper Great Lakes Connecting Channels Study, Management Committee 1988).

anoxia: The absence of oxygen necessary to sustaining most life. In aquatic ecosystems, this refers to the absence of dissolved oxygen in water (Environment Canada *et al.* 1988).

antifouling agents: Various chemical substances added to paints and coatings to combat mildew and crustaceous formations, such as barnacles, on the hulls of ships.

beneficiation: A process whose purposes are either to yield a desired mineral product in finished form for immediate use by consumers (e.g., coal, asbestos) or to recover a concentrated product amenable to further processing by smelting and/or refining (applies mostly to base metal ores) (Marshall 1982).

benthic: Of or living on or in the bottom of a water body (Upper Great Lakes Connecting Channels Study, Management Committee 1988). See also *benthos*.

benthos: The plant and animal life whose habitat is the bottom of a sea, lake, or river (Soil Conservation Society of America 1982).

bioaccumulation: A general term describing a process by which chemical substances are ingested and retained by organisms, either from the environment directly or through consumption of food containing the chemicals (Government of Canada 1991). See also *biomagnification*.

biochemical oxygen demand (BOD): The amount of dissolved oxygen required for the bacterial decomposition of *organic* waste in water (Environment Canada *et al.* 1988).

biodegradable: Capable of being broken down by living organisms into inorganic compounds (Arms 1990).

biological diversity (biodiversity): The variety of different species, the genetic variability of each species, and the variety of different ecosystems that they form (Wildlife Ministers' Council of Canada 1990).

biomagnification: A cumulative increase in the concentration of a persistent substance in successively higher levels of the food chain (Environment Canada *et al.* 1988). See also *bioaccumulation*.

biomass: As measured by ecologists, the dried weight of all organic matter in the *ecosystem*. In the energy field, any form of organic matter (from both plants and animals) from which energy can be derived by burning or bioconversion (e.g., fermentation) (Wells and Rolston 1991).

biosphere: Total of all areas on Earth where organisms are found; includes deep ocean and part of the atmosphere (Arms 1990).

biota: Collectively, the plants, microorganisms, and animals of a certain area or region (Wells and Rolston 1991).

bloom (also known as **algal bloom**): A relatively high concentration of *phytoplankton* that is readily visible in a body of water as a result of proliferation during favourable growing conditions generated by nutrient or sunlight availability (Wells and Rolston 1991).

BOD: See *biochemical oxygen demand*.

CFCs (chlorofluorocarbons): Gaseous synthetic substances composed of chlorine, fluorine, and carbon. They have been used as refrigerants, as aerosol propellants, as cleaning solvents, and in the manufacture of plastic foam. CFCs are suspected of causing ozone depletion in the stratosphere.

chlor-alkali plants: Plants that produce chlorine (for use in bleaching, chemical manufacturing [e.g., production of *chlorinated organic compounds*], water purification) and caustic soda (for use in making soap and paper), by electrolysis of brine. Worldwide, two processes are in common use: the diaphragm cell process and the mercury cell process. A new development in cell technology is the membrane cell (modified from Considine and Considine 1989). The mercury cell process is now tightly regulated to prevent mercury contamination, and its use in Canada has greatly declined.

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[1] Source for the definition is in parentheses within or at the end of the definition; some of the terms defined elsewhere in the glossary are noted by means of italics.

chlorinated organic compounds (also known as **organochlorines** or **chlorinated organics**): Chlorine-containing *organic* compounds, in some cases containing oxygen and other elements such as phosphorus. Includes many pesticides and industrial chemicals (Wells and Rolston 1991). Examples are *dioxins, furans, PCBs, DDT, dieldrin, HCB*, and *HCH*.

chlorophenols (also known as **chlorinated phenols**): A group of toxic chemicals created by the chlorination of *phenols*. Used as preservatives in paints, drilling muds, photographic solutions, hides and leathers, and textiles. Also used as herbicides and insecticides and, most commonly, for wood preservation (Wells and Rolston 1991). An example of a chlorophenol is pentachlorophenol.

chronic toxicity: Toxicity marked by a long duration that produces an adverse effect on organisms. The end result of chronic toxicity can be death, although the usual effects are *sublethal* (e.g., inhibition of reproduction or growth). These effects are reflected by changes in the productivity and population structure of the community (Upper Great Lakes Connecting Channels Study, Management Committee 1988). See also *acute toxicity*.

coliform: A group of bacteria used as an indicator of sanitary quality in water. The total coliform group is an indicator of sanitary significance because the organisms are usually present in large tracts of humans and other warm-blooded animals, and exposure to them in drinking water causes diseases such as cholera (Wells and Rolston 1991).

contamination: The introduction of any foreign, undesirable physical, chemical, or biological substance into the environment. Does not imply an effect (see *pollution*). Usually refers to introduction of human-made substances (adapted from Wells and Rolston 1991).

DDD (dichlorodiphenyldichloroethane): A breakdown product of *DDT*.

DDE (dichlorodiphenyldichloroethylene): A breakdown product of *DDT*. DDE is produced in most animals when the body attempts to rid itself of DDT. DDE is routinely measured rather than only DDT, because DDE is the most fat-soluble of the DDT breakdown products; thus, of all the compounds that make up total DDT (DDT and its metabolites), DDE is the most easily measured in the fat of animals or in eggs (Bishop and Weseloh 1990).

DDT (dichlorodiphenyltrichloroethane): A synthetic insecticide introduced for widespread use just after World War II. Because this *chlorinated organic compound* is persistent and tends to bioaccumulate, most uses of DDT were banned in 1974. Registration of all DDT products was discontinued in 1985. However, the use and the sale of existing stocks of DDT products were allowed until December 31, 1990 (Bishop and Weseloh 1990).

dieldrin: A synthetic pesticide, in use since 1948 as an agricultural soil and seed treatment to kill fire ants, grubs, wireworms, root maggots, and corn rootworms. By 1975, use was restricted, and now dieldrin can be used only for termite control (Bishop and Weseloh 1990).

dioxins and furans: Popular names for two classes of *chlorinated organic compounds*, known as polychlorinated dibenzo-p-dioxins (**PCDDs**) and polychlorinated dibenzofurans (**PCDFs**). Only a few of the 75 PCDDs and 135 PCDFs are highly toxic. The most toxic dioxin is 2,3,7,8-tetrachlorodibenzo-p-dioxin (**2,3,7,8-TCDD**), although tolerance to this compound varies considerably among species. Dioxins and furans are formed either as by-products during some types of chemical production that involve chlorine and high temperatures or during combustion where a source of chlorine is present. Elevated levels of 2,3,7,8-TCDD in the environment are linked to effluents from previous 2,4,5-trichlorophenol manufacturing, such as in the Love Canal area. Dioxins, including 2,3,7,8-TCDD, can also occur in airborne particulate material from incinerators that burn trash containing chlorinated compounds and in exhaust from diesel engines. Chlorine bleaching of kraft wood pulp is another source of 2,3, 7,8-TCDD (Bishop and Weseloh 1990).

ecoclimatic province: A broad area within which similar macroclimate leads to similar ecosystems developing on similar soils (adapted from Ecoregions Working Group, Canada Committee on Ecological Land Classification 1989).

ecoclimatic region: A generally broad area within which similar regional climate leads to similar ecosystems developing on similar soils (adapted from Ecoregions Working Group, Canada Committee on Ecological Land Classification 1989). Ecoclimatic regions are subdivisions of *ecoclimatic provinces*.

ecoprovince: Unit defined in the ecological land classification system. An ecoprovince is a subdivision of an *ecozone* and is composed of a number of similar *ecoregions*.

ecoregion: Unit defined in the ecological land classification system. An ecoregion is a subdivision of an *ecoprovince* and is composed of a number of similar ecodistricts.

Ecosphere: Refers to the entire global ecosystem that comprises atmosphere, lithosphere, hydrosphere, and *biosphere* as inseparable components (from Chapter 1).

ecosystem: An integrated and stable association of living and nonliving resources functioning within a defined physical location. The term may be applied to a unit as large as the entire Ecosphere. More often it is applied to some smaller division (adapted from Burnett *et al.* 1989).

ecozone: Large, terrestrial ecosystem unit that contains distinctive sets of nonliving and living resources that are ecologically related as a system (Wiken 1986). This level of the ecological land classification system was developed for use in the first State of the environment report for Canada[1].

effluent: A liquid waste material that is a by-product of human activity (e.g., liquid industrial discharge or sewage), which may be discharged into the environment (adapted from Wells and Rolston 1991). In mining, effluents are discharges from a mine, mill, smelter, or refinery that contain used water, reagents, metals, and other substances from the various processes that take place during the recovery of minerals and metals from the ore. Mine water that is pumped directly from mines is often discharged with other effluents. Effluents are usually treated to remove metals, reagents, and other substances before release to a settling pond. Water from all sources is often reused many times within the plant.

endangered: In this report, refers to an official designation assigned by the Committee on the Status of Endangered Wildlife in Canada. The designation is assigned to any indigenous species or subspecies or geographically separate population of fauna or flora that is threatened with imminent extinction or extirpation throughout all or a significant portion of its Canadian range. See also *extinct, extirpated, threatened*, and *vulnerable*.

environmental impact assessment: The critical appraisal of the likely effects of a proposed project, activity, or policy on the environment, both positive and negative (Gilpin 1986).

eutrophic: Pertaining to a body of fresh water rich in nutrients and hence in living organisms (Arms 1990).

eutrophication (also known as **nutrient enrichment**): The process of overfertilization of a body of water by nutrients that produce more organic matter than the self-purification processes of the water body can overcome (Schwarz *et al*. 1976). Eutrophication can be a natural process or it can be accelerated by an increase of nutrient *loading* to a water body by human activity (Upper Great Lakes Connecting Channels Study, Management Committee 1988).

exotic species: Species that are not native and have been intentionally introduced or have inadvertently infiltrated an area (Environment Canada *et al*. 1988).

extinct: In this report, refers to an official designation assigned by the Committee on the Status of Endangered Wildlife in Canada. The designation is assigned to any species or subspecies or geographically separate population of fauna or flora formerly indigenous (native) to Canada but no longer known to exist anywhere. See also *endangered, extirpated, threatened*, and *vulnerable*.

extirpated: In this report, refers to an official designation assigned by the Committee on the Status of Endangered Wildlife in Canada. The designation is assigned to any indigenous species or subspecies or geographically separate population of fauna or flora no longer known to exist in the wild in Canada but occurring elsewhere. See also *endangered, extinct, threatened*, and *vulnerable*.

fledging: Term usually applied to the acquisition by a young bird of its first true feathers; when the process is complete the bird is fledged and may for a short time be described as a fledgling (Campbell and Lack 1985).

flyway: A geographic migration route for birds, including the breeding and wintering areas that it connects (Lapedes 1978). The Pacific Flyway, one of four in North America, runs north–south along the mountainous areas of the west.

food chain: A specific nutrient and energy pathway in ecosystems proceeding from producer to consumer (Wells and Rolston 1991). Along the pathway, organisms in higher *trophic levels* gain energy and nutrients by consuming organisms at lower trophic levels (Environment Canada *et al*. 1988).

food web: Complex intermeshing of individual *food chains* in an ecosystem (Wells and Rolston 1991).

furans: See *dioxins and furans*.

greenhouse effect: A warming of the Earth's atmosphere caused by the presence in the atmosphere of certain gases (e.g., water vapour, carbon dioxide) that absorb radiation emitted by the Earth, thereby retarding the loss of energy from the system to space (modified from Chapter 22). The greenhouse effect has been a property of Earth's atmosphere for millions of years. Today, because people are affecting the proportions of gases in the atmosphere, it is thought to be causing a rise in average global temperatures. This rise is also referred to as greenhouse warming and greenhouse gas warming.

groundfish (also known as **bottom fish**): Those species of fish that normally occur on or close to the seabed (Organisation for Economic Co-operation and Development 1990), such as cod and haddock.

ground-level ozone (also known as **tropospheric ozone**): Ozone (O_3) that occurs near the surface of the Earth. It is a pollutant of concern in *smog* because of its toxic effects (adapted from Arms 1990).

groundwater: Water occurring below the ground surface that may supply water to wells and springs (Upper Great Lakes Connecting Channels Study, Management Committee 1988). Groundwater occupies pores, cavities, cracks, and other spaces in bedrock and unconsolidated surface materials (modified from Whitton 1984).

habitat: The environment in which a population or individual occurs. The concept of habitat includes not only the place where a species is found, but also the particular characteristics of that place, such as climate or the availability of suitable food and shelter, which make it especially well-suited to meet the life-cycle needs of that species (Forestry Canada 1991).

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[1] Bird, P.M., and D.J. Rapport. 1986. State of the environment report for Canada. Ottawa: Environment Canada.

half-life: The period of time in which a substance loses half of its active characteristics (used specifically in radiological work); the amount of time required for the concentration of a pollutant to decrease to half of the original value through natural decay or decomposition (Upper Great Lakes Connecting Channels Study, Management Committee 1988).

halons: *Hydrocarbons* (usually methane or ethane) in which the atoms of hydrogen have been replaced by atoms of halogens, such as fluorine, chlorine, or bromine. The two most widely used halons are bromotrifluoromethane (halon 1301) and bromochlorodifluoromethane (halon 1211), which are fire extinguishing agents. The numbering system reflects the number of carbon, fluorine, chlorine, and/or bromine molecules in the halogenated agent (adapted from Eckroth 1984).

hazardous waste: Waste that poses a risk to human health or the environment and requires special disposal techniques to make it harmless or less dangerous (from Chapter 14).

HCB (hexachlorobenzene): Used in synthesizing organic compounds and as a fungicide. Also known as perchlorobenzene (adapted from Lapedes 1978).

HCH (hexachlorocyclohexane): A systemic (meaning that it affects a whole bodily system, such as the nervous system) insecticide toxic to flies, cockroaches, aphids, and boll weevils. Also known as benzene hexachloride (Lapedes 1978).

HDPE (high-density polyethylene): Rigid plastic, often used for containers for dairy products or shampoo. Accepted in many plastic recycling programs.

heavy metals: Metallic elements with relatively high atomic weights (≥ 5.0 specific gravity), such as lead, cadmium, and mercury. Generally toxic to plant and animal life in even relatively low concentrations (Wells and Rolston 1991). Generally not required as *nutrients*.

hydrocarbons: *Organic* compounds containing only hydrogen and carbon (adapted from Wells and Rolston 1991). Crude oil consists, for the most part, of a complex mixture of hydrocarbons.

indicator species: An organism that simply indicates the presence or absence of any particular factor, such as heavy metals (Martin and Coughtrey 1982). Sometimes used loosely as synonymous with *monitor species*.

inorganic: Matter other than plant or animal, and not containing a combination of carbon/hydrogen/oxygen as in living things (Wells and Rolston 1991).

integrated resource management: The management of two or more resources in the same general area; commonly includes water, soil, timber, grazing land, fish, wildlife, and recreation (Forestry Canada 1989).

kraft pulp mill: Produces paper made primarily from wood pulp produced by the sulphite pulping process. Produces comparatively unbleached, coarse paper of great strength (Wells and Rolston 1991).

land capability classes: Classes provided by the Canada Land Inventory to rate the suitability of land for agriculture, forestry, outdoor recreation, ungulates, and waterfowl. For each category, seven capability classes were established to rate the suitability of land for that use. Class 1 has the highest capability or potential; class 7, the lowest (modified from Lang and Armour 1980).

leachate: Solution containing dissolved or suspended materials in water that has percolated through solids such as soils, solid wastes, and rock layers (adapted from Upper Great Lakes Connecting Channels Study, Management Committee 1988).

leaching: Washing out of soluble substances by water passing down through soil. Leaching occurs when more water falls on the soil than is lost by evaporation from the surface. Rainwater running through the soil dissolves mineral nutrients and other substances and carries them via groundwater into water bodies (adapted from Arms 1990). The leaching of mercury and other heavy metals into water supplies is believed to be a serious consequence of *acidic deposition*.

life zones: Canada contains seven life zones (see page 6-11). Three of these correspond to terrestrial *ecozones*, three others are composed of an aggregation of similar ecozones, and the seventh represents Canada's marine waters (see Table 6.2).

loadings: Total mass of contaminants to a water body or to the land surface over a specified time (e.g., tonnes per year of phosphorus) (adapted from Upper Great Lakes Connecting Channels Study, Management Committee 1988).

macronutrient: An element, such as potassium and nitrogen, essential in large quantities for plant growth (Lapedes 1978).

mass balance: An approach to evaluating the sources, transport, and fate of contaminants entering a water system as well as their effects on water quality. In a mass balance budget, the amounts of a contaminant entering the system less the quantity stored, transformed, or degraded must equal the amount leaving the system. If inputs exceed outputs, pollutants are accumulating and contaminant levels are rising. Once a mass balance budget has been established for a pollutant of concern, the long-term effects on water quality can be simulated by mathematical modelling and priorities can be set for research and remedial action (Environment Canada *et al.* 1988).

monitoring: The process of checking, observing, or keeping track of something for a specified period of time or at specified intervals (Soil Conservation Society of America 1982).

monitor species: A species that indicates the presence or absence of any particular factor (see *indicator species*) and allows for regular surveillance and quantification of how much of the factor is present (Martin and Coughtrey 1982).

nitrogen fixation: Conversion of gaseous (atmospheric) nitrogen (N_2) to compounds such as ammonia (NH_3). Carried out in ecosystems mainly by bacteria of the genus *Rhizobium* (Arms 1990).

non-point source: Source of *pollution* in which pollutants are discharged over a widespread area or from a number of small inputs rather than from distinct, identifiable sources (Environment Canada *et al.* 1988). Examples include eroding croplands, urban and suburban lands, and logged forest lands. See also *point source*.

nonrenewable resources: Natural resources that can be used up completely or else used up to such a degree that it is economically impractical to obtain any more of them (Arms 1990) (e.g., coal, crude oil, metal ores). Chapter 1 differentiates between nonrenewable (fossil fuels and radioactive elements) and nonreplenishable (metals and minerals) resources, but this distinction has not been adhered to in other chapters.

nutrient: Any element or compound that an organism must take in from its environment because it cannot produce it or cannot produce it as fast as it needs it (Arms 1990). As pollutants, any element or compound, such as phosphorus or nitrogen, that fuels abnormally high organic growth in aquatic ecosystems (e.g., *eutrophication* of a lake).

nutrient enrichment: See *eutrophication*.

old-growth (also known as **ancient**): A descriptive term attributed to forests that generally have a significant number of huge, long-lived trees, many large, standing dead trees, numerous logs lying about the forest floor, and multiple layers of canopy created by the crowns of trees of various ages and species (modified from Chapter 10).

organic (adj.): Describes compounds based on carbon, and also containing hydrogen, with or without oxygen, nitrogen, or other elements (Wells and Rolston 1991). Organic originally meant "of plant or animal origin," and it is still sometimes used in this way. For example, "organic waste" can mean food scraps, manure, sewage, leaves, etc.; "organic fertilizer" can mean manure; "organic deposits" can mean peat or other plant material in soil; "organic nutrients" can mean nutrients derived from decayed plant material. However, now that organic compounds are routinely created by people, the word "organic" is also used to refer to synthetic organic compounds, as in "organic pollution" (which can include toxic human-made organic compounds). See *chlorinated organic compounds*.

organic (noun): A human-made organic compound (e.g., DDT).

organochlorine: See *chlorinated organic compound*.

overburden: Material of any nature, consolidated or unconsolidated, that overlies a deposit of useful materials, ores, or coal, especially those deposits that are mined from the surface by open cuts (Lapedes 1978). Soils are often stored, to be used later in reclaiming the mine site. Other overburden materials may be used for construction purposes.

ozone layer: See *stratospheric ozone*.

Pacific Flyway: See *flyway*.

PAHs (polycyclic aromatic hydrocarbons): Carcinogenic compounds released into the environment from atmospheric emissions, especially the burning of fossil fuels. Sources include thermal power plants, coke ovens, sewage, wood smoke, and used lubricating oils (Wells and Rolston 1991).

PCBs (polychlorinated biphenyls): A group of 209 isomers that differ from one another in the number and relative position of the chlorine atoms on the biphenyl frame. A small number of the isomers have toxicological properties similar to those of *TCDD* and are thought to account for the bulk of PCB-induced toxicity in animals. In use since 1929, the low flammability of PCBs made them useful as fire retardants in insulating and heat-exchanging fluids used in electrical transformers and capacitors. The same property made them useful as lubricating oils. They were also used as plasticizers and waterproofing agents and in inking processes used to produce carbonless copy paper. Industrial producers of PCBs voluntarily cut back PCB production in 1971. In Canada, PCB uses were regulated in 1977, and importation of all electrical equipment containing PCBs was banned after 1980 (Bishop and Weseloh 1990).

PCDD and PCDF: See *dioxins and furans*.

pelagic: Pertaining to organisms that swim or drift in a sea or lake, as distinct from those that live on the bottom (see *benthic*) (Oxford University Press 1984). Includes plankton, many fish species, and oceanic birds.

pentachlorophenol: See *chlorophenols*.

permafrost: Perennially frozen layer in the soil, found in alpine, arctic, and antarctic regions (Arms 1990).

permafrost degradation: A decrease in thickness or areal extent of *permafrost* because of natural or artificial causes (e.g., climatic warming and/or change of terrain conditions, such as disturbance or removal of an insulating vegetation layer by fire or human means) (Brown and Kupsch 1974).

persistent toxic substances: Any toxic substance with a *half-life* in water greater than eight weeks (Upper Great Lakes Connecting Channels Study, Management Committee 1988).

pesticide: Substances, usually chemicals, used to kill unwanted plants and animals (Government of Saskatchewan 1991). Includes herbicides, insecticides, algicides, and fungicides (Upper Great Lakes Connecting Channels Study, Management Committee 1988).

pesticide residue: Refers to *pesticides* that remain in food, soil, and water after applications. Many of the 5 000 different chemicals are toxic substances that penetrate fruits and vegetables and cannot be washed off (Government of Saskatchewan 1991).

PET (polyethylene terephthalate): A polyester resin used to make films or fibres (Lapedes 1978). A clear plastic that is accepted by many plastic recycling programs.

pH: A numerical expression of the concentration of hydrogen ions in solution — pH 0–<7 is acidic, pH 7 is neutral, and pH >7–14 is basic or alkaline.

phenol: A caustic, poisonous, crystalline acidic compound present in coal tar and wood tar.

phenolics: Any of a number of compounds with the basic structure of *phenol* but with substitutions made onto this structure. Phenolics are produced during the coking of coal, the incomplete combustion of wood, and the operation of gasworks and oil refineries, and from human and animal wastes and the microbiological decomposition of organic matter (Upper Great Lakes Connecting Channels Study, Management Committee 1988).

photochemical smog: See *smog*.

phytoplankton: Minute, microscopic aquatic vegetative life; plant portion of the *plankton*; the plant community in marine and freshwater situations that floats free in the water and contains many species of algae and diatoms (Upper Great Lakes Connecting Channels Study, Management Committee 1988). See also *zooplankton*.

plankton: Collective noun for organisms that drift around in water because they are not capable of swimming against currents in the water (Arms 1990). See also *phytoplankton* and *zooplankton*.

point source: A source of *pollution* that is distinct and identifiable (Environment Canada *et al.* 1988). Includes smokestacks and outfall pipes from industrial plants and municipal sewage treatment plants.

pollution: The release by humans, directly or indirectly, of substances or energy into the environment, which results or is likely to result in deleterious effects: i.e., causing harm to living resources and life, being hazardous to human health, hindering human activities, or impairing the quality of the environmental resources and reducing amenities (modified from Wells and Rolston 1991).

population: A group of organisms of the same species living within a specified region (Wells and Rolston 1991).

primary wastewater treatment: First step in sewage treatment to remove large solid objects by screens (filters) and sediment and organic matter in settling chambers (Wells and Rolston 1991). See also *secondary wastewater treatment* and *tertiary wastewater treatment*.

recovery: The recovery of energy by using components of waste as fuel. Can also refer to the extraction of materials of value from the waste stream.

recruitment: The rate at which young organisms enter the adult population. A measure of the success of reproduction.

recyclable: Refers to such products as paper, glass, plastic, used oil, and metals that can be reprocessed instead of being disposed of as waste (Government of Saskatchewan 1991).

regeneration (also called **reforestation**): The renewal of a forest crop by natural or artificial means. Renewal by self-sown seed or by vegetative means, such as root suckers, is termed natural regeneration. Renewal by sowing or planting is artificial regeneration (Forestry Canada 1991).

renewable resource: Natural resource (e.g., tree biomass, fresh water, fish) whose supply can essentially never be exhausted, usually because it is continuously produced (Arms 1990). Chapter 1 differentiates between renewable (organisms and their products) and replenishable (air, water, soil, and climate) resources, but this distinction has not been adhered to in other chapters.

secondary wastewater treatment: After *primary wastewater treatment*, removal of *biodegradable* organic matter from sewage using bacteria and other microorganisms, inactivated sludge, or trickle filters. Also removes some of the phosphorus (30%) and nitrate (50%) (Wells and Rolston 1991). See also *tertiary wastewater treatment*.

second growth: A second forest that develops after harvest of the original forest (Forestry Canada 1989).

seismic lines: Strips where the land surface has been bulldozed for the purpose of seismic exploration for petroleum reserves. Survey crews travel along these strips and use various surface disturbances to map the underlying geological structure by measuring the returning vibrations.

smog: Literally a contraction of "smoke" and "fog"; the colloquial term used for photochemical fog, which includes ozone and numerous other contaminants (from Chapter 2); it tends to provide a brownish haze to the atmosphere.

soil compaction: The compression of soil as a result of vehicle traffic, especially that of heavy equipment (Forestry Canada 1989).

soil erosion: The detachment and movement of soil by the action of wind (wind erosion) and moving water (water erosion) (Lapedes 1978).

species: A group of individuals that share certain identical physical characteristics and are capable of producing fertile offspring (Burnett *et al.* 1989).

stratosphere: The layer of the atmosphere between about 10 and 50 km above the Earth's surface within which temperatures rise with increasing altitude (modified from Chapter 23).

stratospheric ozone (also known as the **ozone layer**): Ozone (O_3) that is formed in the stratosphere from the conversion of oxygen (O_2) molecules by solar radiation. Ozone absorbs much ultraviolet radiation and prevents it from reaching the Earth (adapted from Arms 1990).

sublethal: Involving a stimulus below the level that causes death (Upper Great Lakes Connecting Channels Study, Management Committee 1988).

succession (also known as **ecological succession**): Short-term (1 000 years or less) change in a biotic community. The process whereby opportunistic plants and animals recolonize an area that has been disturbed (e.g., when a crop field is abandoned and left for nature to redevelop). A series of temporary communities develop according to a pattern that, in the absence of major disturbances, is predictable. The final mature, or climax, stage (an example is an *old-growth* forest) is in equilibrium with (i.e., determined by) the regional climate and the local substratum, topography, and water conditions (adapted from Odum 1989).

sulphite pulp mill: See *kraft pulp mill*.

summerfallow: Land left unsown, usually for a season, to conserve moisture in the soil and to allow accumulation of nitrogen (Standing Committee on Agriculture, Fisheries, and Forestry 1984).

sunspot cycle: Variation of the size and number of sunspots in an 11-year cycle that is shared by all other forms of solar activity (Lapedes 1978).

sustainable development: Development that ensures that the use of resources and the environment today does not damage prospects for their use by future generations (National Task Force on Environment and Economy 1987).

sustainable use: Use of an organism or ecosystem at a rate within its capacity for renewal or regeneration (Wildlife Ministers' Council of Canada 1990).

sustained yield: The yield that a forest, cropland, water body, or other resource base can produce continuously at a given intensity of management (Forestry Canada 1991). Not necessarily sustainable.

tailings: Material rejected from a mill after most of the recoverable valuable minerals have been extracted (Whiteway 1990). Tailings are generally finely ground rock particles that are transported as a water slurry to a storage area, known as a tailings pond, at the mine site. Usually the tailings composition is similar to that of the parent ore body and may therefore contain metals, sulphides, salts, or radioactive minerals.

TCDD: See *dioxins and furans*.

tertiary wastewater treatment: Removal of nitrates, phosphates, chlorinated compounds, salts, acids, metals, and toxic organic compounds after *secondary wastewater treatment* (Wells and Rolston 1991). See also *primary wastewater treatment*.

threatened: An official designation assigned by the Committee on the Status of Endangered Wildlife in Canada. The term describes any indigenous species or subspecies or geographically separate population of fauna or flora that is likely to become *endangered* in Canada if the factors affecting its vulnerability do not become reversed. See also *extinct*, *extirpated*, and *vulnerable*.

total ozone: The ozone present in a column of Earth's atmosphere. Total ozone includes both *ground-level* and *stratospheric ozone*.

toxaphene: Toxic *chlorinated organic compound* used as an insecticide (Lapedes 1978).

toxicity: The inherent potential or capacity of a material to cause adverse effects in a living organism (Wells and Rolston 1991).

trophic: Relating to processes of energy and nutrient transfer from one or more organisms to others in an ecosystem (Wells and Rolston 1991).

trophic level: Functional classification of organisms in a community according to feeding relationships; the first trophic level includes green plants, the second level includes herbivores, and so on (Upper Great Lakes Connecting Channels Study, Management Committee 1988).

trophic status: A measure of the biological productivity in a body of water. Aquatic ecosystems are characterized as oligotrophic (low productivity), mesotrophic (medium productivity), or *eutrophic* (high productivity) (Environment Canada *et al*. 1988).

troposphere: Layer of the atmosphere that contains about 95% of the Earth's air and extends about 6–17 km up from the Earth, depending upon latitude and season. The troposphere ends at the tropopause, the point at which atmospheric temperature starts to increase instead of decrease as one moves farther from the Earth (modified from Arms 1990).

urban place (or **urban area**): As defined by Statistics Canada, an area that has a population of at least 1 000 concentrated within a continuously built-up area, at a density of at least 400 per square kilometre (from Chapter 13). In this report, "city" means a large urban place, with a population of 100 000 or more, and "town" means any smaller urban place.

VOC (volatile organic compound): The term used to describe the organic gases and vapours that are present in the air. They are believed to be involved in *ground-level ozone* formation, and some VOCs are toxic air pollutants (Hilborn and Still 1990).

vulnerable: An official designation assigned by the Committee on the Status of Endangered Wildlife in Canada. The term describes any indigenous species or subspecies or geographically separate population of fauna or flora that is particularly at risk because of low or declining numbers, occurrence at the fringe of its range or in restricted areas, or for some other reason, but is not a *threatened* species. See also *endangered*, *extirpated*, and *extinct*.

waste rock: Valueless rock (unmineralized or weakly mineralized) that must be fractured and removed to gain access to or upgrade ore (Lapedes 1978). It may contain low concentrations of metals or sulphides and is often stored in waste dumps on site.

water erosion: See *soil erosion*.

wet deposition: A process of precipitation whereby acidic chemicals, including dilute sulphuric and nitric acids and sulphates, are deposited in the form of rain, snow, fog, etc. See also *acidic deposition*.

wetland: Land that has the water table at, near, or above the land surface or that is saturated for a long enough time to promote wetland or aquatic processes and various kinds of biological activity that are adapted to the wet environment (National Wetlands Working Group, Canada Committee on Ecological Land Classification 1988). Includes fen, bog, swamp, marsh, and shallow open water.

wind erosion: See *soil erosion*.

zooplankton: Microscopic animals that move passively in aquatic ecosystems (Lapedes 1978). See also *phytoplankton* and *plankton*.

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Quantity	Symbol	Unit name
Area	ha	hectare
	km²	square kilometre
Concentration	ppm	part per million
	ppmv	part per million by volume
	ppmdv	part per million dry volume
	ppb	part per billion
	ppbv	part per billion by volume
	ppt	part per trillion
	pptv	part per trillion by volume
	ng/m³	nanogram per cubic metre
	µg/m³	microgram per cubic metre
	mg/m³	milligram per cubic metre
	µg/dL	microgram per decilitre
	mg/L	milligram per litre
	ng/g	nanogram per gram
	µg/g	microgram per gram
	mg/kg	milligram per kilogram
	µeq/L	microequivalent per litre
	DU	Dobson Unit; 100 DU equals an imaginary layer of pure ozone gas 1 mm thick at standard sea level temperature and pressure

Equivalents	a) Liquids	b) Solids
	1 mg/L = 1 ppm	1 mg/kg = 1 ppm
	1 µg/L = 1 ppb	1 µg/kg = 1 ppb
		1 ng/kg = 1 ppt

Quantity	Symbol	Unit name
Energy	Btu	British thermal unit
	MJ	megajoule
	GJ	gigajoule
	PJ	petajoule
	EJ	exajoule
	MW	megawatt
	KW.h	kilowatt hour
	TW.h	terawatt hour
	KV	kilovolt
	W/m²	watt per square metre
Flow	m³/s	cubic metre per second
	kg/d	kilogram per day
	t/d	tonne per day

Quantity	Symbol	Unit name
Length	nm	nanometre
	µm	micrometre
	mm	millimetre
	cm	centimetre
	m	metre
	km	kilometre
Pressure	kPa	kilopascal
Radiation	Bq	becquerel
	Bq/m²	becquerel per square metre
	Bq/kg	becquerel per kilogram
	mSv	millisievert
Time	s	second
	h	hour
	d	day
	yr	year
Volume	mL	millilitre
	L	litre
	dam³	cubic decametre
	m³	cubic metre
Weight	ng	nanogram
	µg	microgram
	mg	milligram
	g	gram
	kg	kilogram
	t	tonne
	kt	kilotonne
	Mt	megatonne

SI Prefixes

Prefix	Symbol	Multiplying factor
exa	E	10^{18} (1 000 000 000 000 000 000)
peta	P	10^{15} (1 000 000 000 000 000)
tera	T	10^{12} (1 000 000 000 000)
giga	G	10^{9} (1 000 000 000)
mega	M	10^{6} (1 000 000)
kilo	K	10^{3} (1 000)
hecto	h	10^{2} (100)
deca	da	10^{1} (10)
deci	d	10^{-1} (0.1)
centi	c	10^{-2} (0.01
milli	m	10^{-3} (0.001)
micro	µ	10^{-6} (0.000 001)
nano	n	10^{-9} (0.000 000 001)
pico	p	10^{-12} (0.000 000 000 001)
femto	f	10^{-15} (0.000 000 000 000 001)

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